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Electrical Components Division

The Bendix Corporation
Electrical Components
Division

Sidney, New York 13838

Materials Investigation and Tests for the Development of Space Compatible Electrical Connectors

Final Report
Phase I
Tasks I through IV
June 1 through
November 30, 1970

MSFC Contract
NAS8-26054

Prepared for
National Aeronautics and
Space Administration
George C. Marshall
Space Flight Center
Huntsville, Alabama
35812

Report

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Abstract

Relevant literature, reports, papers, periodicals and suppliers data sheets have been reviewed to select candidate metals, platings, rigid dielectrics and elastomers for use in future space compatible electrical connectors. Materials have been selected in light of the extreme environment of earth originated space missions; atmospheric conditions including pressure, humidity and salt corrosion, reduced pressure high oxygen cabin conditions, space vacuum approaching 1×10^{-10} Torr, and temperature extremes from plus 200°C to minus 200°C. The mechanics of cold welding have been studied to aid the selection of metals and platings. The candidate organic materials have been selected for resistance to outgassing and flammability, as well as dielectric and mechanical properties. A test program is recommended to confirm the material selections.

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REPORT

Final Report - Phase I

Materials Investigations and Tests
for the
Development of Space Compatible Electrical Connectors

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1.0 General

1.1 The following reports describe and summarize the results of each of the five tasks as outlined in Bendix Engineering Proposal 897 for Phase I

Task I	-	Contact Development
Task II	-	Shell Development
Task III	-	Structural Dielectrics
Task IV	-	Elastomeric Seal Materials
Task V	-	Digital Efficiency Study

1.2 The detailed reports for Tasks I and II have been combined into a single section because of the overlapping nature of the studies. Tasks III and IV are reported in separate sections and are included herein. The Task V report, because of its extreme difference in scope and subject, is submitted under separate cover.

2.0 Summary

2.1 Phase I required an accumulation of data such as reports, papers, periodicals, and supplier's literature as applicable for each of the five Tasks. This has been done and the relevant material is sorted. As indicated in the following pages, a considerable amount of literature has been reviewed in detail. Several individuals and companies have been contacted by letter and telephone regarding the subjects of each task. In general the contacts have been helpful in supplying information required for the studies.

2.2 The work of Phase I has uncovered materials which appear to better meet the needs of a space oriented electrical connector than heretofore used. Materials have been found which are lighter and stronger than those now used for connector shells. For contacts, the principle concern is electrical conductivity and in this regard several high conductivity materials are proposed. Coupled with the above, several materials which the literature indicate have minimal cold welding tendency are proposed as platings for shells and contacts. In some cases a study is necessary to determine the feasibility of plating the material selected. Organic materials have been found which have

known outgassing and flammability characteristics. Several of these materials are considered non-flammable, others have very low weight loss rates. These organic materials are proposed for use as structural dielectrics and elastomeric seals. It cannot be over emphasized that the use of these materials will probably cause some design and performance trade-offs in connectors as they are known today.

2.3 Some of the anticipated problems are, for example, contact finishes which have an optimum atomic structure and hardness to resist cold welding tend to have higher electrical resistivity than those finishes in common use now. To compensate, a high conductivity base metal can be used but again not without compromise. The tensile strength of high conductivity material is generally considerably less than beryllium-copper which is now used for socket contacts and as a result may require an auxiliary spring member. Another anticipated trade-off will result in a reduction in the wire range sealing capability when a non-flammable fluorocarbon elastomer with 200-250% elongation replaces a silicone rubber with 400-450% elongation. This high elongation is required not only for wire sealing but also for the actual molding process. In order to provide deep convoluted wire sealing webs in a grommet the large portion of the mold pin which forms the space between webs must be drawn through the much smaller web area upon completion of the molding process and thus requires high allowable elongation.

2.4 Detailed in each section of this report are the recommendations for Phase II. The subsequent work will be aimed at confirming the results of Phase I literature search with respect to just how well the candidate materials will meet the respective cold welding, outgassing, and flammability requirements of future electrical connectors. Phase II will also investigate the aforementioned design and performance trade-offs to determine the actual compromise, if any, that may result from the incorporation of the newly proposed materials. This will largely be accomplished by noting the relative ease of fabrication of tests samples required later in Phase II.

TASKS I & II

Final Report - Phase I

Task I - Contact Development and Task II - Shell Development

3.0 Introduction

3.1 The purpose of Tasks I and II is to discuss various metals as potential contact and shell materials and study how a space environment may affect them. A section on radiation is presented in which the effects and importance it has on various metallic materials are discussed. Also included are conclusions as to whether radiation should be considered a significant factor in future work.

4.0 Radiation Types

4.1 Solar Radiation

4.1.1 Energy leaving the sun consists of electromagnetic radiation, high speed protons, and other particles. The output of light and heat is fairly consistent, but the output of ultraviolet radiation, radio waves, and charged particles varies due to solar flares which are usually of short duration.

4.1.2 Solar radiation covers the spectrum of wavelengths shorter than 10^{-4} μ to wavelengths longer than 10^{8} μ. Table 1 (page 20) indicates the wavelength range of various types of electromagnetic radiation.

4.1.3 The non-penetrating portion of the solar spectrum lies between .01 and 15 μ. About 99% of the energy of the solar spectrum lies between 0.3 and 4.0 μ.

4.2 Radiation in Space

4.2.1 This includes X-rays, steady ultraviolet and solar radiation, and cosmic rays. Data from Explorer ICY, Explorer IV and Sputnik III indicate the radiation intensity increases by a factor of several thousand between 180 and 975 miles altitude, reaching as much as 10 Roentgens per hour. Data from Pioneer I indicates a rapid decay in radiation intensity beyond 17,000 miles from the earth. During periods of solar flares, radiation may be much higher than normal.

4.2.2 The earth's geomagnetic field becomes important in terrestrial space because it traps incoming solar and cosmic radiation to form the Van Allen radiation belt. Actually, this consists of two belts, the first characterized by a high density of energetic protons extends from about 1400 to 3400 miles from the earth and the second characterized by a high density of low energy electrons extends from about 8000 to 12,000 miles from the earth.

4.3 Electromagnetic Radiation

4.3.1 This consists largely of sunlight, but includes ultraviolet light, X-rays, and gamma rays. Observations of cosmic ray fluctuations associated with solar flares indicate intense pulses of gamma rays are injected into space.

4.4 Effects of Radiation on Metallic Materials

4.4.1 Charged particles, because of their interaction with atomic nuclei, expend their energy in the process of ionization. Since metallic materials are good conductors, this energy is dissipated as heat with no significant property changes.

4.4.2 Uncharged particles (e.g.; neutrons) can penetrate material freely. If one collides with an atom the neutron is usually deflected with a reduced velocity onto a new course. The atom is usually knocked to a new "non-equilibrium position". Such collisions result in the occurrence of lattice defects such as vacancies, interstitialcies, and thermal and dislocation "spikes".[2]

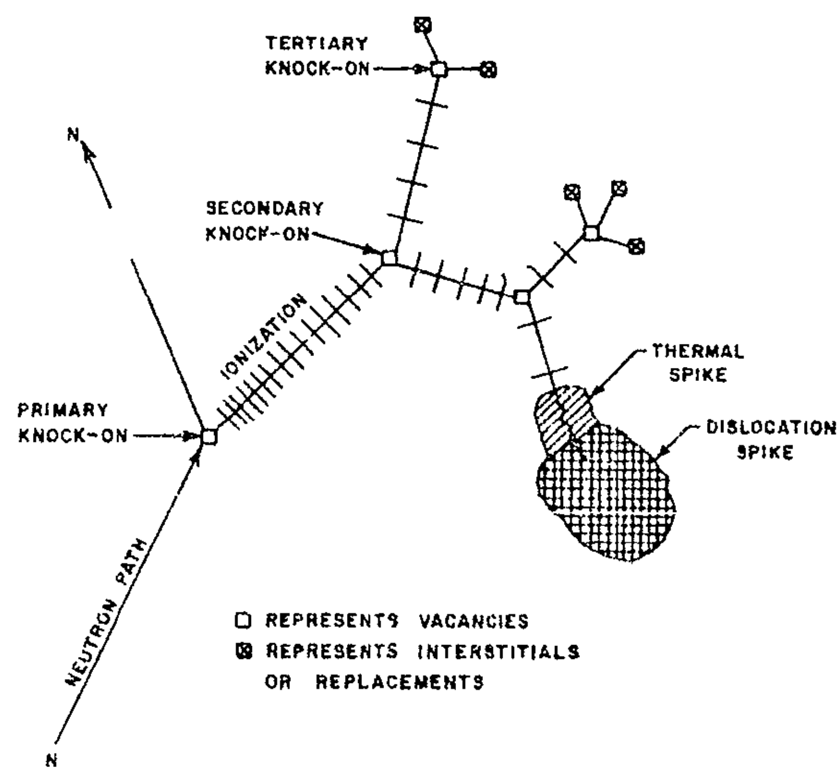

Figure 1.
Effect of Single Collision of High Energy Neutron with a Primary Knock-on Atom[2]

2 - See Bibliography in Appendix

4.4.3 Vacancies and interstitialcies may hinder subsequent dislocation movement through the material. Both thermal and dislocation spikes cause heating and result in atomic re-arrangement over a very small localized area.

4.5 Importance of Radiation on Metallic Materials.

4.5.1 It appears that radiation presents no real problem to metals except at extremely high doses (e.g.; 1×10^{20} neutrons/cm^2). Generally, under these conditions, some embrittlement would occur resulting in an increase in hardness and YP/TS ratio, an effect far more noticeable in face centered cubic materials than body centered ones [4]. In addition, a rise in the ductile-brittle transition point and a decrease in the creep rate could be expected. Occasionally, also a rise in thermal and electrical resistivity may be encountered. An exception to this general pattern was observed with beryllium which after a similar exposure exhibited a 15% decrease in hardness [1]. It is thought that protons would have an effect similar to neutrons, but gamma radiation appears to have little effect.

4.5.2 All metals should show some damage to surface properties from solar flares and the radiation belts but none should show damage through one milligram/cm^2 (e.g.; 6 μ of magnesium)[1]. In certain cases, metallic whiskers can be nucleated by irradiation or neutron bombardment. Copper, cadmium, and zinc shows these tendencies and their electroplates are the worst offenders probably because of their coherency strains.

4.6 Summary and Conclusions

4.6.1 Only after very high doses of radiation, such as might be encountered from reactor fluxes, would really noticeable changes occur in the mechanical and physical properties of metallic materials. In space, these radiation levels are very unlikely.

4.6.2 Table 2[2] indicates the exposures to radiation necessary to bring about appreciable property changes, and from this it can be seen that at least 30 years exposure to neutron radiation is required before significant damage to metallic materials occurs.

4.6.3 In conclusion, it can be said that the metal of a connector is, relatively speaking, insensitive to radiation damage [3] and it is recommended that radiation be ignored in any future work.

5.0 <u>Shell Material Selection</u>

5.1 As mentioned in the previous report, shell candidates considered worthy of further study were required to possess better strength values than 6061-T6 aluminum at +400 °F. This decision reduced markedly the number of magnesium and aluminum alloy possibilities but had no effect on others.

5.2 A subsequent decision was made that only alloys not heavier than titanium should be considered. This was done because it was thought that the only real advantage that high strength, high specific gravity alloys could offer would be a possible weight reduction brought about by a redesign. However, this advantage becomes meaningless when one realized that selected high strength low specific gravity alloys would probably offer the same promise.

5.3 The recommendation of an alloy for further study is based on general properties (e.g.; strength/weight ratio, specific gravity, availability, etc.). The fabrication mode associated with any particular alloy (e.g.; working or casting) is not considered significant at this stage except that a balanced selection would probably optimize chances of eventual success in subsequent testing.

5.4 Magnesium Alloys

5.4.1 In the previous report, mention was made that magnesium alloys should not be used in space applications because of the high sublimation rate exhibited in vacuum. For example, the Langmuir equation predicts a loss of .004 inch/year for magnesium at +400 °F. However, Rittenhouse[1] points out that the the theoretical rates expressed are maxima and practical rates always fall well below this.

5.4.2 In view of this information, plus the fact that magnesium would only be used with a protective low vapor pressure coating (or plating), it was concluded that Mg alloys should be regarded as shell material candidates. A review of the available alloys show that the best two both show strength/weight ratios superior to 6061-T6 at +400 °F. Accordingly, these two alloys are recommended for further study.

5.5 Aluminum

5.5.1 The strongest aluminum alloys at +400 °F appear to be concentrated in the 2000 and the 7000 series. Unfortunately, the latter, (Al-Zn-Mg-Cu typical composition) are susceptible to overaging or softening on long exposures to +400 °F which would render them unsuitable for further study. The 2000 series (Al-Cu alloys with possibly small additions of

Mn, Mg, and Ni) fortunately are not susceptible to this phenomenon. Several promising casting alloys are now available and one of these together with an alloy from the 2000 series are recommended for further study.

5.6 Titanium

5.6.1 Titanium alloys possessing high strengths together with moderate weights (specific gravity 4.4 g/cc) offer really high strength/weight ratios and so are logical contenders for shell material candidates. The corrosion resistance of titanium is generally very satisfactory.

5.6.2 A serious limitation in the use of these alloys is that dangerous and sometimes castastrophic attack may occur if they come into contact with certain liquids (e.g.; liquid 0_2). Fortunately, these limitations are well understood [5, 6] and, of course, should be taken into account when the spacecraft design is finalized (assuming, of course, that titanium is the eventual shell material choice).

5.6.3 Of the titanium alloys considered, two have been selected for further study.

5.7 Steels

5.7.1 In the previous report, steels were briefly evaluated. All types, except possibly stainless, were eventually discounted because it was thought that the inherent characteristics, such as a ductile-brittle transition, magnetic properties, etc. were potential problem areas.

5.7.2 Even the best stainless type considered (A 286) possessed a tensile strength not as good as those exhibited by most titanium alloys, yet it weighs almost twice as much.

5.7.3 It is now felt that the disadvantages associated with steels outweigh the advantages and no further action is contemplated with these alloys.

5.8 Nickel, Cobalt, and Molybdenum Alloys

5.8.1 In the previous report, it was stated alloys in these groups should not be regarded as serious contenders. This opinion is unchanged and no further action will be taken with these alloys.

5.9 Miscellaneous Alloys

5.9.1 Lockaloy

5.9.1.1 Kawecki Berylco's (KBI) introduction of Lockalloy (62% Be 38% Al)

was the culmination of developments originated at Lockheed. The material, developed specifically for the aerospace industry, has a high modulus and low weight which make it especially desirable. In the strength spectrum, it fills the gap between magnesium and aluminum alloys and the higher strength titanium and beryllium alloys. Laboratory data appears sparse (especially at elevated temperatures) but that available indicates a strength/weight ratio of approximately 19.2 can be expected at +400°F as compared to that of 5.5 for Al 6061-T6 alloy.

5.9.1.2 The main limitations of Lockalloy are twofold; first the high cost, which is expected to fall somewhat in the future, and second the care required in processing (e.g., machining) which demands special attention. This, if required, would be carried out at the Navigation and Controls Division of Bendix where special equipment is available. Lockalloy cannot be hardened by heat treatment.

5.9.2 Beryllium

5.9.2.1 This material, also marketed by KBI, is even lighter and stiffer than Lockalloy and so must be regarded as a contender. Data on elevated temperature properties is also rather sparse but sufficient to indicate good strength retention at 400°F. The metal is the principal heat sink material used in the aerospace industry [8] and has found wide previous use.

5.9.2.2 Limitations associated with Beryllium include an inherent brittleness and the fact that it appears more prone to radiation damage than most other metals. Like Lockalloy, it has a high cost and processing difficulties (e.g.; machining) which, if required, would also be carried out by the Navigation and Controls Division of Bendix. Beryllium cannot be hardened by heat treatment.

5.9.3 Composites

5.9.3.1 It would seem that, in any new material study, composites merit some attention. These materials, capable of very high strengths and yet usually very light, are composed of small high strength filaments dispersed in a lower strength matrix.

5.9.3.2 Although composite technology is still being developed, sufficient knowledge has already been acquired to indicate the tremendous potential of these materials in the near future. Presently, the tremendously high cost of filaments is a major barrier to composite advancement, but indications are that this will be reduced sharply with time and increased production as indicated in Table 3.

5.9.3.3 Another factor, more efficient processing techniques, is also bringing about cost reductions[9]. Here, for example, United Aircraft claims that a 25% filament cost reduction may be obtained simply by the use of increased diameter filaments. Other limitations of the material include the fact that due to its high hardness only grinding is possible. The second is the relatively poor mechanical properties at 90° to the filament direction. Composites may or may not be amenable to heat treatment, depending upon the composition.

6.0 Final Shell Material Selection

6.1 It is thought logical that the shell candidates should be of several basic materials, rather than one or two families, so optimizing the chances of eventual success. Nine were selected and the details of these, together with those of the original standard 6061-T6 aluminum are included in Table 4. They comprise four categories, (1) magnesium, (2) aluminum, (3) titanium and (4) miscellaneous alloys. These are discussed in the following paragraphs.

6.2 Magnesium Alloys

6.2.1 Of the magnesium alloys reviewed, the two with the best strength/weight ratio at +400°F are recommended for further study. The first of these is alloy HM31A which is a magnesium-thorium alloy recommended for elevated temperature service (600-850°F) in aircraft, missiles, and space vehicles. Developed primarily as an extrusion alloy it is produced by the Dow Chemical Company.

6.2.2 The second is QE22A, a magnesium-silver-rare earth casting alloy which is claimed to have the highest yield strength of any cast magnesium alloy up to +480°F. Patented by Magnesium Elektron of England (where the designation MSR is employed) it is produced under license by several U.S. Foundries. Both magnesium alloys can be heat treated.

6.3 Aluminum Alloys

6.3.1 The two aluminum alloys recommended for further study possessed the best strength/weight ratios at +400°F commensurate with availability. The first is alloy 2219 one of the aluminum copper alloys which is capable of high strength retention at elevated temperatures. It is a wrought alloy produced by Alcoa and is available in a variety of forms.

6.3.2 The second is alloy K01 which, like 2219, is basically an aluminum copper alloy but with minor additions of silver, titanium, and other elements. K01 is a casting alloy which gives strength levels some 20% better than those obtained with the well established aluminum-silicon 350 series. Being a relatively new material, applications are still being found. Developed originally by the Electronic Specialties Company, it is now produced by several foundries in the U.S. One of these is located at the Bendix-Energy Controls Division. Both aluminum alloys specified can be heat treated.

6.4 Titanium Alloys

6.4.1 All the titanium materials reviewed had very good strength levels, which were much better than the magnesium and aluminum alloys selected. Therefore, selection of titanium materials was made on general all-round properties. The first selected Ti-6Al-4V is the most widely used and is considered the general purpose titanium alloy. It has good fabricating properties and can be heat treated.

6.4.2 The second is CP 70 which is commercially pure titanium with a guaranteed yield point of 70,000 psi minimum at room temperature. Although this strength level is inferior to that of Ti-6Al-4V, it does possess better formability, and probably better plating characteristics. It cannot be hardened by heat treatment.

6.5 Miscellaneous Alloys

6.5.1 Lockalloy

The various aspects of this alloy have been discussed previously.

6.5.2 Beryllium

The various aspects of this alloy have also been discussed previously.

6.5.3 Composites

6.5.3.1 Magnesium-boron composite was selected as a candidate since it is probably the most voluminous composite material produced and hence the most readily available. Produced by the General Technologies Corporation of Reston, Virginia, it is made by a continuous casting process.

6.5.3.2 Magnesium-boron composites with 30% filament content have very high strengths (138,000 psi tensile at room temperature) and are yet very light (density .071 lbs/in.^{3}). On a strength/weight basis, this is the best shell candidate material to be evaluated.

6.5.3.3 At the conclusion of the Literature Survey, a total of 31 inquiries (letters and telephone calls) had been made to various firms, organizations, institutions, and universities and a total of 26 replies received (84%). Details are given in Table 5.

6.6 Summary - Shell Material Selection

6.6.1 Nine shell candidate materials (ref. Table 4) are recommended for further study. It is believed this choice is a well balanced one which optimizes chances of success during the envisaged detailed test program which comprises Phase II.

6.6.2 It is further believed that this material selection emphasizes the potential usage of newer rather than well established materials. Platings and/or coatings are expected to be required.

7.0 Pin Contact Material Selection

7.1 At the time of writing the previous report, the Literature Survey was confined to copper alloys only. Since then, some silver base alloys have also been evaluated. In all, over 30 materials (both Cu and Ag base, comprised of both production and experimental alloys, were reviewed. The only selection criteria applied was a minimum tensile strength of 70, 000 psi and minimum conductivity of 80% IACS. Others such as strength/weight ratios were ignored here in view of the relatively small masses involved and most alloys examined (Cu base) possessed almost identical specific gravities.

7.2 Six alloys passed the selection criteria and full details of these are given in Table 6. Five of these are high copper alloys (Cu 98% min.) and one is a silver-copper eutectic alloy. With these alloys, high mechanical properties are obtained by cold work, heat treatment, or a combination of the two. Generally, these six alloys offer higher tensile levels and electrical conductivities than are obtained from materials currently used in similar applications. It is felt that the increased tensile levels will be beneficial in minimizing or preventing the cold welding tendency which is expected to be more of a problem with pins and sockets than with shells. Platings are expected to be required.

7.3 At the conclusion of the Literature Survey, a total of 22 inquiries (letters and telephone calls) had been made to various firms, organizations, institutions, and universities, and a total of 18 replies received (82%). Details are given in Table 5.

7.4 Summary - Pin Contact Material Selection

7.4.1 Six materials (ref. Table 6) are recommended for further study as pin contact candidates. All are capable of possessing tensile levels of > 70, 000 psi with electrical conductivity values 80% IACS. Plating is expected to be required.

8.0 Socket Contact Material Selection

8.1 As outlined in the previous report, +200°C (+392°F) represents the upper temperature limit to which copper base spring materials can be subjected for long periods. It was therefore decided that as the optimum socket material may or may not be a copper alloy, two parallel literature surveys would be carried out, the first for copper base and the second for non-copper base materials. In both, the strength/weight selection criterion was not used in view of the relatively small masses involved.

8.2 Copper Base Alloys

8.2.1 The selection criterion of a minimum tensile strength of 90,000 psi and a minimum conductivity of 50% IACS previously decided upon was found to be too severe as the survey progressed as only two alloys passed it. It was therefore decided that some relaxation either in tensile strength and/or conductivity would have to be made so that the number of candidate materials could be increased.

8.2.2 In the previous report, it was stated that "several beryllium-copper grades suffer a marked deterioration in their spring properties at 150°C which would preclude their use in a space compatible connector". However, the degree of accord between the literature survey indications and practical usage on this point differ as Berylco 25 for example is frequently used at temperatures up to 200°C with no apparent ill effects although the survey indicated long term service usage should be limited to 150°C maximum.

8.2.3 In view of the above, it was decided that in this case, alloy selection should be guided by practical usage rather than by the Literature Survey. With the selection criterion being amended to a minimum tensile strength of 90,000 psi and a minimum conductivity of 20% IACS, Berylco alloys 25 and 165 could be selected for further study. Seven alloys were now found to pass requirements. One of these, however, (phosnic bronze) was deleted from the list in view of its similarity in composition and properties to another candidate - Telnic bronze.

8.2.4 Candidates now included 3 beryllium copper alloys (Berylco 10, 25 and 165), 2 experimental alloys, Olin 0195 and a copper-nickel-titanium alloy developed by American Metal Climax in which the U.S. Army is apparently showing an active interest, and Telnic bronze.

8.2.5 Full details of the six alloys recommended for further study are given in Table 7. All of these owe their properties to a combination of working and heat treatment. Platings are expected to be required.

8.2.6 At the conclusion of the Literature Survey, a total of 19 inquiries (letters and telephone calls) had been made to various firms, organizations, institutions, and universities, and a total of 15 replies received (79%). Details are given in Table 5.

8.3 Non-Copper Base Alloys

8.3.1 As stated in the previous report, a strength and conductivity criterion would be difficult to apply against the materials reviewed in view of the wide variation in material properties encountered. Instead, selection was based on general all round properties. Of the alloys reviewed, four are recommended for further study and full details of these are given in Table 7. Electrical conductivities range from about 40% IACS for molybdenum-titanium-zirconium and beryllium down to 7% for beryllium-nickel, and strengths from approximately 70,000 psi upwards. Mechanical properties are obtained by working and/or heat treatment. Platings are expected to be required. It was decided that various steels, previously under active consideration, should not be selected in view of their generally poor conductivities.

8.3.2 At the conclusion of the Literature Survey a total of 16 inquiries (letters and telephone calls) had been made to various firms, organizations, institutions, and universities, and a total of 12 replies received (75%). Details are given in Table 5.

8.4 Summary - Socket Contact Material Selection

8.4.1 It is believed that the ten alloys (ref. Table 7) recommended for further study represent the broadest possible spectrum of likely socket materials available today. This should maximize the chances of successfully finding a suitable material in the future testing program.

9.0 Auxiliary Metallic Connector Part Selection

9.1 Snap Rings and Springs

To minimize the number of variables which will be encountered in Phase II, it is recommended that these two items be kept as 17-7 PH steel. This material is a good spring steel, widely available, and moderately priced.

9.2 Rivets

There appears to be no justification for changing from the current material which is 300 series stainless steel.

9.3 Grounding Strap Assemblies

It is recommended that a grounding strap not be offered in view of the fact that although the work undertaken so far has given an indication of new materials a further program would then be required to find a suitable joining method for joining the strap to the shell.

9.4 Summary

It is felt that the continued usage of snap rings, springs, and inserts in already proven materials is a logical selection in view of their good record in the past and the fact that their shortcomings do not appear sufficient to warrant their exclusion.

10.0 Plating Material

10.1 The Literature Survey carried out as Phase I of this contract indicated that a virtually endless selection of plating material candidates could be justified [10, 11, 12, 13]. Unfortunately the testing program brought to light were not directly applicable to our project with the possible exception of studies at Battelle[13].

10.2 The list of materials recommended by the above survey, plus those whose worth was dictated by experience, made up a number which was obviously too large. As a consequence, it was decided that, to keep the envisaged testing program within reasonable limits, it would be necessary to select a number of the most promising materials (seven seemed the best total) and test these as platings, with the understanding that some or perhaps all of them might be replaced as the test program continued. In fact, in an extreme situation, it could eventually be decided that the best shell and contact materials could be unplated ones. Reduction of the number of plating candidates to seven meant that several promising materials had to be disregarded. For shells, this meant omission of various ruthenium and rhenium alloys and cobalt, and for contacts omission of ruthenium alloys, platinum and platinum alloys, palladium and palladium alloys, and tin.

10.3 Another decision taken was to limit the platings to elements (instead of alloys) for the following reasons:

a. There were fewer elements to choose from than alloys hence selection was easier.

b. Plating with elements would, generally speaking, be easier than plating with certain little used alloys.

c. Element platings would give the widest possible selection of plating characteristics which should optimize chances of eventual success.

10.4 As this survey was aimed at the possible use of newer materials, it was logical to expect that the characteristics of at least some of those selected would not be completely known. Events proved that this was

indeed the case and applied both to platings and to materials being plated to the extent that at the time of writing, investigational work is still being carried out to determine whether some envisaged plating is indeed possible.

10.5 The widespread use of under-platings is envisaged in view of the high diffusion coefficients of many substitute materials (e.g.: high Cu alloys) where diffusion into the outer plating may materially affect the plating performance.

10.6 The summary of the cold welding problem survey and the conclusions reached relevant to platings were:

a. Elements with a close packed hexagonal (CPH) atomic structure generally possess a better cold welding (CW) resistance than those with cubic atomic structures.

b. Materials with high hardness, yield stress, elastic modulus and low ductility are preferred for CW resistance.

c. High melting point materials have better CW resistance.

d. The use of softer platings against harder platings may be advantageous as the softer ones may act as lubricants.

10.7 With these points in mind, the seven selected platings (or coatings) for shells and contacts was made. Details are given in Table 8, and include both conductive platings and dielectric coatings for shells, and both hard and soft platings for contacts.

10.8 Final Plating Selection (Shells)

10.8.1 Ruthenium - An element having a CPH structure and high melting point (2250°C) is a logical plating choice [10, 14] and should, by all accounts find much increased usage in the near future. Its main limitation at this time is that large scale plating has not yet been carried out industrially [15], and therefore some unknowns regarding its plating characteristics still exist. The Literature Survey indicates it has great potential. The electrical conductivity is approximately 16% IACS.

10.8.2 Osmium - This is another metal with a CPH structure and a high melting point (3000°C). Due to health hazards, osmium plating has up to recently not been possible but now Englehard Industries have developed a safe reliable process. Osmium possess a very high elastic modulus which enhances its claim to further study. Like ruthenium, its plating characteristics are still partly unknown. The electrical conductivity is approximately 18% IACS.

10.8.3 Rhenium - This is another member of the platinum family possessing a CPH structure and again the melting point is high (3180°C). Rhenium possesses low electrical conductivity, only 9.1% IACS. Its throwing power is very poor and variations in plating thickness usually result[15].

10.8.4 Electroless Nickel - The main asset of this plating is its high hardness. Attempts at Bendix-ECD to ultrasonically (cold) weld parts together plated with electroless nickel failed completely.

10.8.5 Chromium - This is a very hard plating also which should possess an inherent resistance to cold welding. Currently used on the Zero G connector used in the Skylab program. (NASA Spec. 40M39580).

10.8.6 Rhodium - The first choice of the industrial platers contacted [15, 16] for our application is rhodium. Its plating characteristics are well known and reliable. The electrical conductivity is approximately 35% IACS.

10.8.7 Oxide Coatings (Al_2O_3 of MgO) - Anodized coatings possess extreme hardnesses, which should prove cold welding resistant and have extreme wear resistance in vacuum.

10.8.8 At this time it is not known what NASA's requirements would be regarding the shell plating. Hence, both conductive and dielectric materials are included in the candidate list.

10.9 Final Plating Selection (Contacts)

10.9.1 Ruthenium, Osmium, Rhenium, Rhodium — Already discussed under shell plating candidates.

10.9.2 Autronex W (capable of Knoop hardness 400/450) has excellent anti-galling characteristics and corrosion resistance. The use of this against itself or against other platings may produce a satisfactory space contact. This material and the other golds recommended for further study all possess good electrical conductivity.

10.9.3 Au -.1% Co - This plating is included as a candidate in view of the work carried out at Battelle [13]. A rhodium underplate maybe used as this is likely to be the most effective barrier material to prevent substrate diffusion.

10.9.4 Pure Gold (24K) - It is the intention to obtain a pure relatively hard gold (approximately 130 Knoop hardness). This type of gold is similar to the gold-cobalt alloy. However, it should be more resistant to oxidation at elevated temperatures.

10.9.5 At the conclusion of the Literature Survey, a total of 5 inquiries (letters and telephone calls) had been made to various firms, organizations, institutions, and universities and a total of 5 replies received (100%). Details are given in Table 5.

10.10 Summary

10.10.1 Shell Platings - Six conductive platings and one dielectric material (ref. Table 8) are recommended for further study. The six platings are all elements which gives a wide spectrum of plating material characteristics.

10.10.2 Contact Platings - The seven platings (ref. Table 8) recommended represent a balanced selection of materials which should provide the maximum possibility of eventual success.

10.10.3 As might be expected with a material survey aimed at the possible usage of newer materials and platings, the feasibility of some material/plating combinations are not completely known at this time.

10.10.4 Nine shell, six pin and ten socket materials are recommended for future study. One of these, beryllium, is both a shell and socket candidate. Of the twenty four materials selected, twenty have known plating characteristics and the processing of these can be costed normally. The remaining four have largely unknown plating characteristics and for these, a Literature Survey is recommended which would be aimed at determining the platability or otherwise of each. (It should be noted that these four are the most expensive of the twenty four.) Listing of these two sets of materials are given in Tables 9-1 and 9-2.

11.0 Proposed Test Program - Phase II

11.1 It is proposed that Phase II of this program consist of extensive testing. Basically, this falls into three separate areas as outlined below.

11.2 The initial effort regarding the 20 materials would involve acquiring a minimum of 14' of each in either rod or strip form only, and plating as indicated in Tables 10, 11, and 12. After plating, some samples should be considered standards and others would be subjected to environmental, plating adhesion, and metallurgical testing.

11.3 The effort for the other four materials would involve the Literature Survey which would start after the plating effort of the twenty had been completed. At the conclusion of the Literature Survey, a review of the results would be presented to NASA. Materials then considered promising would be subjected to environmental, plating and metallurgical testing. Other materials would be disregarded.

11.4 The results of the environmental, plating, and metallurgical testing carried out on the various materials would then be reviewed. From these, the quantity of candidate materials would be reduced as indicated below.

Candidate Quantity

	a) Before Plating Adhesion and Metallurgical Testing	b) After a) and Before Vacuum Testing
Shell materials	9	4
Platings/coatings	7	4
Pin materials	6	4
Platings	7	4
Socket materials	10	4
Platings	7	4

11.5 The next part of the effort would involve machining shells and contacts from materials previously found to be successful, plating them with the platings which were successful, and then subjecting every combination to extensive vacuum testing. During this testing, durability and preliminary electrical testing will be carried out, but the main object is to determine whether cold welding will occur. There would be a total of 512 contact pairs undergoing vacuum testing. These would be derived as follows:

4 pin materials and 4 platings	= 16 combinations
4 socket materials and 4 platings	= 16 combinations
16 x 16	= 256 combinations

11.6 One pin and socket of each type will be vacuum tested. This will therefore give 256 contact pairs. In addition to these 256 contact pairs which should have good cold welding resistance, a further 256 contact pairs will be simultaneously vacuum tested. These will be made of materials which should cold weld and so will indicate the extent of the cold welding problem. Additional vacuum testing will be required after the first stage to confirm the good results obtained. The extent of this testing will, of course, remain unknown until the first vacuum testing is completed and results assessed.

11.7 There will be a total of 16 connector shells undergoing vacuum testing. These would be derived as follows:

4 shell materials and 4 platings = 16 combinations

11.8 There will be two areas where cold welding is a possibility. First the engagement pins to the coupling ring and, second, the wave washer to the plug shell. It is proposed that the coupling ring and the plug shell be of the same material and plating in each of the 16 tests, thereby allowing the two cold welding tests to be performed simultaneously.

11.9 The receptacle shell is only in light contact with other metallic parts and the assumption is made that it will not be susceptible to cold welding and can therefore be a standard material throughout the vacuum testing (eg.; aluminum).

11.10 It is felt that cold welding is more likely to occur with contacts rather than with shells, primarily because the former carry current which will increase the heating effect. For this reason, it is proposed that the contacts for vacuum testing be split into two distinct groups, one composed of materials having good cold welding resistance and the other made up of materials having a poor cold welding resistance. The object of this approach is to demonstrate in one test that cold welding is a problem and the good materials selected are capable of overcoming it.

11.11 With shell vacuum testing such a dual-pronged testing program is deemed unnecessary and, hopefully, most of the 16 candidates will have good cold welding resistance. Additional vacuum testing will be required after the first stage to confirm the good results obtained. The extent of this testing will, of course, remain unknown until the first vacuum testing is completed and results assessed.

11.12 The final part of this effort would involve detailed Connector Test Lab testing at Bendix-ECD on contacts and shells made from materials and platings found to be successful on previous testing. Tests carried out here would include durability and electrical (contacts). Both of these tests would be more comprehensive than those carried out during vacuum testing. The main object of this effort is to fully determine the electrical characteristics of contacts. It is expected that at the conclusion of these tests a firm opinion may be expressed as to the optimum materials from which a space compatible connector may be built.

Table 1

Classification of E. M. Radiation by Wavelength

Wavelength -μ	Classification
<.01	X-rays & γ rays
.01 - .2	Far ultraviolet
.2 - .32	Middle ultraviolet
.32 - .38	Near ultraviolet
.38 - .72	Visible
.72 - 1.5	Near infrared
1.5 - 5.6	Middle infrared
5.6 - 1000	Far infrared
>1000	Microwaves & Radiowaves

Table 2

Effect Of Radiation At Neutron Flux Level Of
10^9 Neutrons (Fast)/CM^3/Sec. With Exposure Time

Time at 10^9 n Fast	nvt	Effect on Materials
1 Hr.	3.6×10^{12}	Germanium diodes and transistors lose rectification and amplification.
100 Hrs.	3.6×10^{14}	Cuprous oxide diodes lose rectification.
3000 Hrs.	1.1×10^{16}	Silicon diodes lose rectification.
1 Year	3.2×10^{16}	"Soft" magnetic materials properties degraded, permanent magnets not affected.
30 Years	1×10^{18}	Most metals show higher yield strength.
100 Years	3×10^{18}	Carbon steels have reduced notch impact strength.
3000 Years	1×10^{20}	Carbon steels have severe loss of ductility, yield strength doubled, higher fracture transition temperature
10,000 Years	3×10^{20}	Stainless steel yield strength tripled.
30,000 Years	1×10^{21}	Aluminum and stainless steels ductility reduced but not greatly impaired.

Table 3

Anticipated Composite Cost

Type Material	Time	Cost per pound
Aluminum-Boron	Today(1968)	$2,000 - $3,000
Aluminum-Boron	1970	$500
Aluminum-Boron	1973	$200
Aluminum-Boron	1978	$100
Aluminum-Carbon	1978	$ 50
Titanium-Silicon Carbide	1978	$125

Metal-Matrix Composite Production Forecast

Year	Pounds
1967	100
1968	1,000
1969	10,000
1970	100,000
1973	500,000
1978	Several Million

Composite Usage Forecast (1980's)

Use	Percent Penetration by Composites	Annual Composite Market (millions of dollars)
Aircraft and Aerospace	60	800
Engines and Turbines	40	300
Pumps and Compressors	20	70
Ordnance	50	30
Railroad Equipment	15	60
Building Construction	5	100
Shipbuilding	10	50
Special Uses (machines, structures, etc.)		350
		1,760

TABLE 4

FINAL SHELL MATERIAL CANDIDATE SELECTION

Alloy	Manufacturer	Analysis (Nominal) C	Si	Mn	S	P	Ni	Cr	Mo	V	W	Mg	Cu	Ti	Others	S.G (g/cc)	Y S (400°F) x10³(psi)*	Y.S.(400°F) S.G.	Comments
Aluminum 6061-T6	Alcoa		6					25				1.0	3		Al-Rem	2 7	15	5.5	Included for comparison only
Magnesium HM31A	Dow			1 2								Rem.			Th 3 0	1 81	21	11.7	
Magnesium QE22A	Magnesium Elektron											Rem			Ag 2 5 Zr .7 Rare earth 2 0	1 82	23	12.6	
Aluminum 2219	Alcoa			3									6 3		Al-Rem	2.8	25	8 8	
Aluminum K01	Electronic Specialty Co		15	5								5	5 0	3	Ag 1.0 Fe 15 Al-Rem.	2 8	41	14.9	
Titanium Ti-6Al-4V	Armco									4 0				Rem.	Al 6 0	4.43	112	25	
Titanium C P 70																4.43	34	7 8	Commercially pure titanium.
Lockalloy	Kawecki Berylco														Al 38 0 Be 62.0	2 1	40	19.2	
Beryllium	Kawecki Berylco														Be 98.0 BeO 2 0	1.85	63	34	
Composite Mg - B	General Technologies Corp											70			B 30	1 95	U/K	U/K	

*The available data is not sufficient to enable a standardization of exposure times to +400°F Hence, the exposure times used for the various alloys are listed below

Aluminum 6061-T6	10,000 hours
Magnesium HM 31A	Not stated but data sheet specifies exposures of not greater than 1000 hours at up to 600°F causes virtually no change in properties.
Magnesium QE 22A	Data not available
Aluminum 2219	10,000 hours
Aluminum K01	1,000 hours
Ti - 6 Al - 4 V C P Ti 70	Undetermined exposure time to +400°F Cooled to room temperature and tested
Lockalloy	One hour then cooled to room temperature and tested
Beryllium	One hour then cooled to room temperature and tested Kawecki Berylco stated that other data regarding higher temperature exposure indicated virtually no change in yield at +400°F would occur on longer exposure times than that recorded
Composites	Data not available

TABLE 5

LIST OF INQUIRIES MADE AND REPLIES RECEIVED (TO 11/30/70)
AS PART OF THE LITERATURE SURVEY
FOR POSSIBLE NEW CONTACTS,
PLATINGS AND SHELL MATERIALS

FIRM	DATE OF INQUIRY	DATE OF REPLY	PINS	SOCKETS Cu	SOCKETS N Cu	PLATINGS	SHELLS
AMERICAN WELDING SOCIETY NEW YORK, N. Y.	6-12-70	6-15-70	X	X	X		X
THE WELDING INSTITUTE CAMBRIDGE, ENGLAND	6-12-70	6-18-70	X	X	X		X
ELECTRONICS INDUSTRIES ASSOC. WASHINGTON, D. C.	6-15-70	6-22-70	X	X	X		X
INSTITUTION OF METALLURGISTS LONDON, ENGLAND	6-16-70	-	X	X	X		X
SHEFFIELD POLYTECHNIC SHEFFIELD, ENGLAND	6-17-7-	-	X	X	X		X
SYRACUSE UNIVERSITY SYRACUSE, N. Y.	6-17-70	-	X	X	X		X
BATTELLE MEMORIAL INSTITUTE COLUMBUS, OHIO	6-17-70	6-29-70	X	X	X	X	X
CRANFIELD INSTITUTE OF TECHNOLOGY BEDFORD, ENGLAND	6-17-70	7-2-70	X	X	X		X
MASSACHUSETTS INSTITUTE OF TECHNOLOGY CAMBRIDGE, MASS.	6-22-70	-	X	X	X		X
BENDIX RESEARCH LABORATORY SOUTHFIELD, MICHIGAN	6-25-70	7-10-70	X	X	X		X
ELECTRONICS PROPERTIES INFORMATION CENTER (EPIC) CULVER CITY, CALIFORNIA	7-1-70	7-10-70	X	X	X		X
CARPENTER STEEL COMPANY READING, PENNA.	7-29-70	7-29-70			X		X
INTERNATIONAL NICKEL CO , INC. HUNTINGTON, WEST VIRGINIA	7-29-70	7-29-70			X		
CLIMAX MOLYBDENUM COMPANY GREENWICH, CONN.	7-31-70	7-31-70			X		
ASSOCIATED SPRING CORP. CONN.	7-31-70	7-31-70			X		
AMERICAN SILVER COMPANY FLUSHING, N.Y.	8-7-70	8-7-70			X		
SEL-REX CORPORATION NUTLEY, N. J.	8-10-70	8-10-70				X	
ENGLEHARD INDUSTRIES NEWARK, N. J.	8-3-70					X	
TECHNIC INC. PROVIDENCE, R. I.	7-27-70	7-27-70				X	
DOW CHEMICAL COMPANY MIDLAND, MICHIGAN	6-11-70	6-11-70					X
ALUMINUM COMPANY OF AMERICA NEW KENSINGTON, PENNA.	6-25-70	7-2-70					X
KAISER ALUMINUM ERIE, PENNA	6-25-70	8-4-70					X
HARVEY ALUMINUM TORRANCE, CALIFORNIA	6-25-70	7-7-70					X

FIRM	DATE OF INQUIRY	DATE OF REPLY	PINS	SOCKETS Cu	SOCKETS N Cu	PLATINGS	SHELLS
OLIN METAL RESEARCH LABORATORY NEW HAVEN, CONN.	2-26-70	7-7-70	X	X			X
REYNOLDS METALS COMPANY RICHMOND, VA.	6-26-70	7-9-70					X
REVERE COPPER AND BRASS ROME, N. Y.	6-26-70	7-14-70					X
NATIONAL LEAD COMPANY SALT LAKE CITY, UTAH	6-26-70	8-7-70					X
KAWECKI BERYL CO. INC HAZELTON, PENNA.	6-26-70	6-29-70					X
ARMCO STEEL CORPORATION BALTIMORE, MD.	7-1-70	7-7-70					X
OREGON METALLURGICAL CORP. ALBANY, OREGON	7-1-70	7-6-70					X
COLT INDUSTRIES PITTSBURGH, PENNA	7-1-70	8-4-70					X
TITANIUM METALS CORPORATION WEST CALDWELL, N. J.	7-1-70	7-6-70					X
THE MAGNESIUM ASSOCIATION TULSA, OKLAHOMA	7-1-70	-					X
GENERAL DYNAMICS CORP. SAN DIEGO, CALIFORNIA	7-13-70	7-13-70					X
GENERAL TECHNOLOGIES CORP RESTON, VA.	7-14-70	7-14-70					X
MAGNESIUM ELEKTRON INC SECAUCUS, N. J.	8-6-70	8-6-70					X
COPPER DEVELOPMENT ASSOC. NEW YORK, N. Y.	6-22-70	7-17-70 7-23-70 7-29-70	X	X			
CHASE BRASS AND COPPER CLEVELAND, OHIO	6-23-70	7-10-70	X	X			
HANDY AND HARMAN FAIRFIELD, CONN.	7-13-70	7-27-70	X	X			
WESTINGHOUSE RESEARCH LAB PITTSBURGH, PENNA	7-16-70	7-16-70	X	X			
CALUMET AND HECLA DES PLAINES, ILLINOIS	7-17-70	7-17-70	X	X			
AMERICAN METAL CLIMAX NEW YORK, N. Y.	7-23-70	7-23-70	X	X			
MALLORY AND COMPANY INDIANAPOLIS, IND.	7-30-70	7-30-70	X	X			
BENDIX ENERGY CONTROLS DIV. SOUTH BEND, IND	9-18-70	9-18-70					X
HITCHCOCK INDUSTRIES INC MINNEAPOLIS, MINN.	11-6-70	11-6-70					X
ANACONDA AMERICAN BRASS CO SYRACUSE, N. Y.	11-11-70	11-11-70	X				
PHELPS DODGE COPPER PRODUCTS CORP. ELIZABETH, N. J	11-11-70	11-11-70	X				
LITTLE FALLS ALLOY COMPANY PATTERSON, N.J.	11-12-70	11-12-70 11-13-70	X				
LEA-RONEL INC. WATERBURY,CONN.	1 -16-7-	11-16-70				X	

TABLE 6

PIN CONTACT CANDIDATES

Alloy	Manufacturer	Analysis	T.S. (psi x 1000)	Y.S. (psi x 1000)	% ICAS	Modulus (psi x 10^6)
Cube-alloy	Handy and Harmon	Cu 99.5 Min. Be 0.5	80	63	83	18.7
Amzirc	American Metal Climax	Cu balance Zr 0.10-0.15	70	61	90-95	18.7
Chromium Copper 182	Anaconda American Brass Co.	Cu 99.14 Cr .85 Si .01	70	60	80	Not available in Alloy Digest or Anaconda data sheet
Hitenso 162	Anaconda American Brass Co.	Cu balance Cd 1.0 Fe,Si,Pb,.02 max ea.	90	50	87	16.0
P D 135	Phelps Dodge	Cu 99.0 Cr 0.5 Cd 0.5	83	72	85	20
Copper-Silver Eutectic	Engelhard Ind.	Cu 28 Ag 72	80		77	11.8

TABLE 7

SOCKET CONTACT CANDIDATES

Alloy	Manufacturer	Analysis	Mechanical Properties T. S. (psi x 1000)	Y. S. (psi x 1000)	Conductivity (% IACS)	Modulus (psi x 10^6)
0195	Olin Brass	Cu bal. Sn 0.55% Fe 1.55% P 0.10% Co 0.85%	95	93	50	
Berylco 10	Kawecki Berylco Ind. (KBI)	Cu balance Co 2.5%	110	90	60	19
Berylco 25	KBI	Cu balance Co 0.28% Be 2.08%	230	200	25	18.5
Berylco 165	KBI	Cu balance Co 0.23% Be 1.70%	200	185	30	18.5
Telnic Bronze	Chase Brass and Copper Co.	Cu bal. Te 0.5% Zn 1.0% P 0.2% Pb 0.1% Ni 1.1% Fe 0.1%	95	85	47	16
Cu-Ni-Ti	American Metal Climax	Cu balance Ni 4.8% Ti 2.6%	100	100	42	
T Z M	Climax Molybdenum of Michigan	Mo balance Ti 0.5% Zn 0.08%	145	116	35	46
Beryllium	KBI	Be balance BeO 2.0%	95	60	42	44
Permanickel	International Nickel Co.	Ni bal. Fe 0.6% Ti 0.5% C 0.25%	240	210	11	30
Be - Ni	KBI	Ni balance Be 2.0% Ti 0.5%	200	150	7	30

TABLE 8

SELECTED PLATINGS AND COATINGS FOR SHELL MATERIALS

Ruthenium	Conductive
Rhodium (Stress Free)	Conductive
Osmium	Conductive
Rhenium	Conductive
Electroless Nickel	Conductive
Chromium	Conductive
Oxide Coatings	Dielectric

SELECTED PLATINGS FOR CONTACT MATERIALS

Ruthenium	Conductive
Rhodium	Conductive
Osmium	Conductive
Rhenium	Conductive
Autronex W	Conductive
Au/ .1% Co	Conductive
24 K Au	Conductive

TABLE 9-1

MATERIALS WITH KNOWN PLATING CHARACTERISTICS

(For details see Tables 4, 6, and 7)

Alloy:	Supplier:
Magnesium HM31A	Dow
Magnesium QE22A	Hitchcock Industries
Aluminum 2219	Alcoa
Aluminum K01	Bendix-Energy Controls Div.
Titanium Ti-6Al-4V	Armco
Titanium CP 70	Armco
Cube - Alloy	Handy and Harmon
Chromium Copper 182	Anaconda
Hitenso 162	Anaconda
Copper-Silver Eutectic	Engelhard Ind.
PD 135	Phelps-Dodge
Amzirc	Little Falls Alloys
Cu-Ni-Ti (Experimental)	American Metal Climax
O 195	Olin
Berylco 10	Kawecki Berylco Ind. (KBI)
Berylco 25	KBI
Berylco 165	KBI
Telnic Bronze	Chase Brass and Copper
Permanickel	International Nickel
Beryllium-Nickel	KBI

TABLE 9-2

MATERIALS WITH UNKNOWN PLATING CHARACTERISTICS

(For details see Tables 4 and 7)

Alloy:	Supplier:
Lockalloy	KBI
Beryllium	KBI
Magnesium-Boron Composite	General Technologies Corp.
Molybdenum TZM	Climax Molybdenum of Mich.

TABLE 10

PROBABLE SHELL MATERIALS AND PLATINGS*

Shell Candidates (in strip form)	Plating Candidates
Mg Alloy HM31A	Ruthenium
Mg Alloy QE22A	Rhodium (stress free)
Al Alloy 2219	Osmium
Al Alloy KO1	Rhenium
Ti Alloy Ti-6Al-4V	Electroless Nickel
C P Ti 70 (Commercially pure TI)	Hard Chromium
	Oxide Coating

*To be evaluated during Materials Lab testing (NASA Contract Phase II). Each shell candidate listed is to be tested with each of the plating candidates listed.

TABLE 11

PROBABLE PIN CONTACT MATERIALS AND PLATINGS*

Pin Contact Material	Plating Candidates
Handy & Harman CuBe Alloy	Ruthenium
Am. Metal Climax Amzirc (CuZr)	Rhodium (stress free)
Engelhard AgCu Eutectic Alloy	Osmium
Anaconda 162 or 1622 (CuCd)	Rhenium
Anaconda 182 (CuCr)	Autronex W
Phelps Dodge PD 135 (CuCrCd)	Au/ .1% Co
	24 K Gold (Knoop 160)

*To be evaluated during Materials Lab testing (NASA Contract Phase II). Each pin candidate listed is to be tested with each plating candidate listed.

TABLE 12

PROBABLE SOCKET CONTACT MATERIALS AND PLATINGS*

Socket Contact Material	Plating Candidates
Mo - Ti - Zr	Ruthenium
Beryllium	Rhodium (Stress Free)
Permanickel	Osmium
Be - Nickel Alloy 440	Rhenium
Olin O195	Autronex W
Berylco 10	Au/ .1% Co
Berylco 165	24 K Gold
Berylco 25	
Telnic Bronze	
Cu - Ni - Ti	

*To be evaluated during Materials Lab testing (NASA Contract Phase II). Each socket candidate listed is to be tested with each plating candidate listed.

TASK III

Final Report - Phase I

Task III

Investigation of Structural Dielectric Materials For Electrical Connectors Used in Space Environments

12.0 Introduction

12.1 Our first quarterly report[24] described the overall aims of this part of the investigation including the approaches we have taken to accumulate data on the various materials which appear to have potential for this application. It also included a number of data sheets on these materials.

12.2 This report covers our further progress in the search and includes data on additional materials and a general description of them. It also provides a description of the continuation of this program into Phase II.

13.0 Report

13.1 At this final stage in our literature search for structural dielectric materials suitable for NASA connector applications, we feel we have accomplished what we intended. We have studied a vast number of materials. The majority have been discarded from further consideration for obvious reasons, usually heat resistance or flame resistance. Numerous other materials were eliminated only because there were other materials in the same general group which were superior.

13.2 The list of materials by this time was reduced to approximately thirty which we felt worthy of inclusion in the data sheets which form a part of this report as Table 13. Our intention was to provide as much essential information as possible in these sheets so that we could select the best for further study in Phase II.

13.3 As mentioned in the first quarterly report, information on outgassing in hard vacuums and flammability in oxygen atmospheres was the most difficult to come by.

13.4 The various NASA documents [17, 18, 19, 20] provide the only truly authoritative sources for this information. As expected, the materials we are most interested in have not yet been tested by NASA. However, phone conversations with Mr. D. Supkis of NASA, Houston, and Mr. C. F. Key of Marshall Space Flight Center, Huntsville, were not too encouraging. Both indicate a shortage of completely suitable organic molding compounds. The polyimides and TFE are normally satisfactory. So are the heavily loaded Fluorel (3M) and Viton (duPont) elastomers

which are covered in Task IV. Some attempts have been made by Mr. Supkis [21,22] to overcure these latter materials to a rigid state comparable to a plastic but as expected shrinkage problems have been present and we do not consider this an adequate approach to connector insert molding.

13.5 According to Mr. Key, no epoxy materials have been suitable in a direct flame test under oxygen atmospheres and the rigid silicone materials are not satisfactory. This pretty well wiped out many of those materials which we had felt showed particular promise. However, it might be possible to test in accordance with Test No. 5 of MSFC-Spec-101: Flammability Requirements and Test Procedures for Materials in Gaseous Oxygen Atmospheres [23]. This covers the procedure for electrical potting and coating compounds and consists of a current overload on cables assembled in a connector. This test is considerably less severe than Tests No. 1 and 2 of the above specification and has been a standard test for electrical connectors. The structural dielectric member of a connector would only be exposed to flame when unmated and even then would be well shielded by the metallic component.

13.6 Outgassing requirements posed similar problems in that most of the data from NASA is concerned with temperatures up to 100 °C and vacuum levels down to 10^{-8} Torr, as applied to the ATM program. Our intention was to select materials which would be acceptable by these guidelines and in addition provide low outgassing at 200 °C under 15 psi air as well as extreme vacuum conditions.

13.7 Most of the materials being evaluated do not appear in either ATM Material Control for Contamination Due to Outgassing 50MO2442 Revision R or Outgassing Contamination of Dielectric Materials Used in the ATM Program NASA TM X 53699 [18, 19]. However, these helped tremendously in enabling us to catalog materials in a general sense by similarity with those approved or disapproved.

13.8 There are apparent discrepancies in the former document, such as the listing of diallyl phthalate glass filled, MIL-P-19833, Type GDI-30 without further description as an acceptable material while the sample of GDI-30 supplied by Bendix-ECD with a special high temperature cure was listed as unacceptable. This fairly well typifies the fundamental problem with outgassing tests and shows why the final qualification testing in Phase II will of necessity be done at NASA.

13.9 Outgassing of polymeric materials falls into two categories. Disregarding adsorbed air and moisture, exposure to hard vacuums extracts the low boiling or low molecular weight fragments or additives such as plasticizers, mold releases, waxes, etc. This is accomplished by the vacuum with elevated temperatures accelerating the extraction.

The second category covers the loss of weight through oxidation processes. Here vacuum is likely to be beneficial as it minimizes oxidation through absence of oxygen, as discussed in our First Quarterly Report [24].

13.10 It would therefore appear that any material showing very low weight loss at 200 °C in air would most likely be satisfactory for space exposure. In any case, it is apparent that the choice of a material for general NASA requirements requires that weight loss at temperature be evaluated in earth as well as space environments.

13.11 Mechanical and electrical properties provide no great difficulty as most of the materials described in the data sheets fall within the original guidelines or reasonably close. There does not appear to be any reason for selecting a material because of any unusual superiority in any mechanical or electrical characteristic.

13.12 A comparison of the most suitable materials is facilitated by cataloging them into similar groups. We have therefore done so and included a brief description of the pertinent characteristics of the materials which have influenced our selection of them for further study in Phase II.

13.14 Polyimide Materials

13.14.1 Numerous insulating materials based on polyimides and related polymers are now available. The original, du Pont Vespel, and the later varieties such as Dixon Meldin, Bemol Feuralon P, and the Amide-imide AI-11 supplied by Amoco are essentially suitable only for machined parts or very simple shapes. Because of this they are not considered for further evaluation although their properties are well suited for this application.

13.14.2 However, molding compounds are now available which lend themselves to complex parts. Two basic materials are available, a thermosetting series developed by General Electric and named Gemon and a thermoplastic variety represented by American Cyanamid's XPI series. Liquid Nitrogen Products Corporation markets a glass filled material based on the American Cyanamid polymer and designated as YF 1004.

13.14.3 All these materials warrant a thorough evaluation in Phase II. While the data tabulated covers the materials currently available, we have been advised that further modifications and new materials are pending. The Gemon material 3010 is a long glass fiber filled material designed for compression molding. We have had notable success in transfer molding this material but have been advised by GE that a material tailored for transfer molding is just about ready.

13.14.4 The thermoplastic materials are equally interesting. Initial work done on XPI-MC 154 would tend to indicate somewhat greater ease in molding than Astrel 360 with some loss in heat resistance. The glass filled modifications would tend to provide greater rigidity and stability and probably lower outgassing.

13.14.5 Flammability of polyimides in oxygen atmospheres is in general satisfactory although somewhat inconsistent. du Pont Vespel has been tested a number of times by NASA. It is reported as satisfactory in NASA TMX-53788 [20]. However, results in MSC-02681 [17] would not seem to be that positive. All tests conducted at 16.5 psi oxygen and several tests at 5 psi oxygen showed varying degrees of flammability although the propagation rate exceeded 0.3 inch per second in only one instance.

13.14.6 The Gemon material should be as good as the Vespel. The thermoplastic materials have a considerably lower oxygen index and must be considered doubtful for the most severe categories.

13.15 Silicone Molding Compounds

13.15.1 Several companies are producing silicone molding compounds, notably Dow Corning, Midsil Corporation, and more recently General Electric. Materials from the first two of these are pretty much duplications probably because of the long relationship between the two companies. GE has just started in this field and does not have the extensive line of materials the others market.

13.15.2 The main drawback with these materials lies in the apparent inability of the suppliers to produce a material having good moldability and at the same time have adequate mechanical strength. All materials evaluated to date have shown an inherent weakness in "knitting" properly, resulting in a pronounced tendency to crack, particularly at elevated temperatures. Mineral or silica filled materials are simply too brittle for a reliable connector insert. Glass filled materials having improved impact strength show a greater tendency to crack.

13.15.3 While we will continue to investigate all such materials coming to our attention, on present evidence we must rule out present materials for general usage on the basis of inadequate moldability and durability.

13.16 Polyarylsulfone

13.16.1 The polyarylsulfone material developed by 3M and designated Astrel 360 comes closest of all the thermoplastics to meeting all the requirements. While the characteristics of the material necessitate molding equipment capable of providing high pressures and high temperatures,

both in the injection cylinder and at the mold, the material actually molds unusually well even in complicated connector parts.

13.16.2 Mechanical, thermal, and electrical properties are all adequate. Arc resistance is somewhat lower than expected but should be sufficient for connectors. Outgassing data available from 3M would indicate this also to be satisfactory.

13.16.3 Data on flammability in oxygen atmospheres available at this time from MSC 02681 shows this material to be slow burning but not self extinguishing. It seems possible that the material will only pass the flammability requirements in oxygen when tested as a connector. This and the need for special molding presses appear to be the only shortcomings of Astrel 360.

13.17 Fluorocarbon Plastics

13.17.1 The fluorocarbon plastics as a general class come close to meeting the requirements for a space connector. However, all have limitations which remove them from the list of first choice materials.

13.17.2 Polytetrafluoroethylene (PTFE or TFE) meets all the thermal, flammability, and outgassing requirements. Its chief drawback is its inability to be molded into the complex shapes required of connector inserts. While the material can be machined readily, this would be impractical unless no moldable material was suitable. The radiation resistance of TFE is also questionable. While radiation effects under vacuum are considerably less severe than in air, the overall usefulness of a connector would certainly be reduced by inclusion of TFE as a critical member. Adhesive bonding limitations also must be considered in the selection of the material and TFE is characteristically weak in this area.

13.17.3 Filled versions of TFE do little to improve the basic shortcomings and as a result this material is not given further consideration at this time.

13.17.4 Fluorinated Ethylene Propylene (FEP) being a true thermoplastic provides a solution for the fabrication problems associated with TFE. However, there is still considerable doubt as to whether its moldability is good enough for connector inserts. It lacks the rigidity customarily felt necessary in a structural connector dielectric and adhesive bonding problems still exist. Glass filled versions such as Liquid Nitrogen Processing Corporation Fluorocomp 905 may provide a decisive improvement in several respects. While we do not consider this material a first line candidate, we feel it warrants further consideration in the second phase of this project, in event the higher rated materials fall short.

13.17.5 Chlorinated trifluoroethylene (CTFE) better known as Kel-F from its 3M trade mark is more rigid than FEP but definitely borderline in heat resistance. The glass filled version supplied by LNP as their Fluorocomp 803 provides some improvement but again the overall characteristics of this material leave it in the same category as the FEP materials.

13.17.6 Tefzel, du Pont's ethylene-TFE copolymer, and Kynar, Pennwalt's polyvinylidene fluoride, are both lacking adequate heat resistance and could only be considered if the high temperature extreme is reduced. Otherwise both might be worthy of further examination.

13.18 Polyphenylene Sulfide

13.18.1 Phillips Petroleum has produced a family of polyphenylene sulfide materials they have designated as Ryton PPS. Several forms of the resin are available suitable for fluid-bed coating, laminating, and compression molding. However, we are most interested in the newest product which is suitable for injection molding and available in unfilled and filled versions.

13.18.2 Various fillers have been employed with a compound containing 40% glass fibers appearing at this time to provide optimum characteristics. Data on the materials is quite sparse due to their newness. It is expected that more will be forthcoming from the supplier in the coming months. Additional tests will have to be conducted in Phase II particularly in the outgassing and flammability areas.

13.18.3 This material has an oxygen index of 0.44 or better, meaning it is self-extinguishing in an atmosphere of 44% oxygen and 56% nitrogen. This would indicate a high degree of flame resistance and the probability that modifications in filler could make it acceptable for even the most severe tests.

13.19 Polybutadiene

13.19.1 Recently some interest has been shown in developing electrical molding compounds based on the polybutadiene polymer. Two in particular appear worthy of note: Furane Plastics Epocast X-87104 and Firestone FCR-1261. Neither material appears to have a distinct edge over the better epoxy materials in any single respect although both are new enough that improvements seem certain.

13.19.2 In addition to these the Richardson Company is marketing a family of polybutadiene resins trade marked Ricon. While no specific molding compound is yet available, the resin is suitable for formulating such materials and the overall characteristics should put them in the same category as the others.

13.20 Ekonol

13.20.1 This is a high temperature polyester material developed by Carborundum. It has unusually good heat resistance but can be fabricated into parts only by sintered powder technology coupled to machining. This leaves it in a category similar to TFE and effectively limits its use as far as connectors are concerned.

13.21.2 The material can be filled with metals as well as nonmetallic fillers which might lead to special applications. There is also the possibility that further research might improve its moldability though at the moment this seems unlikely.

13.21 Epoxy Materials

13.21.1 In recent years high performance electrical connectors have largely used either DAP or epoxy molding compounds as the structural dielectric members with epoxies getting the nod where optimum heat resistance and electrical properties were required. These materials still must be considered seriously because of their ease in fabrication and long history of satisfactory service.

13.21.2 While their heat resistance is not as high as some of the other materials, the better ones still show low weight loss at 200-260 °C in air. Moreover flammability has been proven adequate for certain categories [25] and, it is expected, could be improved further if absolutely necessary. However, it is unlikely they would pass the more rigorous of the oxygen flammability tests used by NASA.

13.21.3 A number of epoxy materials have been listed in the table as representative of those available. Epiall 1288BX supplied by Allied Chemical has been used by Bendix for a number of years with exceptional success. Even so we feel that Epiall 1914 (also Allied) and Fiberite E9747 are very likely somewhat superior in heat resistance and flame resistance and may offer improvements in certain processing areas.

13.22 Alkyds

13.22.1 Thermosetting alkyd plastics have been available for some time gaining particular acceptance on automotive ignition distributor blocks and high voltage insulators where arc resistance is of paramount importance. Early materials were used for a while on connectors where their poor resistance to moisture was quickly encountered and they were largely replaced by DAP and epoxy compounds. Since then improvements have been made in the materials by most of the basic suppliers and their original weaknesses largely corrected.

13.22.2 While these materials are not considered first-line condidates, we feel they should be considered for further evaluation in the event the higher rated materials prove inadequate.

14.0 Phase I Conclusions

14.1 Evaluation of the various materials from the data currently available shows a number which warrant further testing in Phase II. While it is difficult to establish a bonafide rating of the materials because of the many factors involved and the considerable difference in the tests conducted, some materials certainly show up as superior to the others. We have therefore broken these into two types, thermosetting and thermoplastic, and further broken these types into groups based on their apparent suitability for connectors.

14.2 Group 1 in both cases includes those materials which show marked superiority in those characteristics important for this application. They contain the least obvious shortcomings in the available data and should be moldable in connector inserts with careful design and proper equipment. In most cases they would not be rated this high on processability alone and it is expected that Phase II may show up limitations in this area.

14.3 Group 2 includes those materials which are not quite as highly rated in all basic characteristics. They may, for example, exhibit somewhat reduced heat resistance but still be adequate in this respect.

14.4 Group 3 includes materials which seem doubtful in some important characteristic or which lack too much data at this time. Subsequent information may improve their status or further modifications remove their questionable features.

14.5 Rating of Structural Dielectric Materials

14.6 Thermosetting Materials:

Group 1:
a. General Electric Gemon 3010 and modifications.
b. Fiberite Corporation Epoxy E9747.
c. Allied Chemical Epiall 1914.

Group 2:
a. American Cyanamid Glaskyd 7100FR and modifications.
b. Allied Chemical Epiall 1288BX.
c. Allied Chemical Epiall 1988 or 2088.

Group 3: a. Furane Plastics Polybutadiene Epocast X87104.

b. Pacific Resins Epoxy EMC500.

c. Firestone Polybutadiene FCR 1261.

14.7 Thermoplastic Materials:

Group 1: a. Minnesota Mining Astrel 360.

b. American Cyanamid Polyimide XPI-MC 154.

c. American Cyanamid Polyimide XPI-MC 154-G10.

d. Liquid Nitrogen Processing Polyimide YF1004.

Group 2: a. Phillips Petroleum Ryton PPS.

b. Liquid Nitrogen Processing, Fluorocomp 905, Glass Filled FEP.

c. Liquid Nitrogen Processing, Fluorocomp 803, Glass Filled CTFE.

15.0 Proposals For Phase II

15.1 Phase I of this program has covered a survey of potential materials for use as the structural dielectric member of a new breed of electrical connectors tailored specifically for NASA requirements.

15.2 Phase II of this program was preconceived to complete the data necessary for the final selection of the material. At the conclusion of Phase I, it is now possible to better document the tests necessary for an accurate decision. We, therefore, propose the following.

15.3 Flame Resistance

15.3.1 We propose to conduct oxygen index evaluations of all the primary materials to arrive at a positive correlation between the materials and hopefully to thereby supplement the go no-go rating now in use. Supkis[22] has indicated that samples with a limiting oxygen index greater than 0.53 or 53% passed the silicone igniter tests while those with a lower index failed. The test is also valuable in determining flammability of materials in a mixed gas system as all samples with a limiting oxygen index greater than 0.40 will be self extinguishing in an atmosphere of 40% oxygen and 60% nitrogen. He also indicates, however, that it cannot distinguish between flaming and glowing combustion and provides little correlation with burn rates.

15.3.2 In addition to this we propose to submit samples to NASA for their flammability tests as it is recognized that this constitutes the final standard. These samples can be submitted prior to completion of our tests or can be delayed until we have effectively removed all but the best materials. Very possibly we will require some modification of the standard upward and downward propagation rate tests if some of our best candidates are to be acceptable.

15.4 Outgassing

15.4.1 We are limited with respect to our ability to conduct outgassing tests at the extreme vacuum and the high temperature simultaneously as well as our ability to analyze the gases evolved. However, we feel we can develop considerable information with the equipment available.

15.4.2 We propose to prepare samples from each of the materials considered, in two or more thicknesses, including at least .032 and .125 inch. We will test these at 392°F (200°C) and room atmosphere and at the same temperature and the maximum vacuum available at Bendix-ECD, approximately 10^{-5} Torr. The weight loss figures obtained from this would give us good guidelines for submitting a limited number of samples to NASA for final approval.

15.4 Moldability

15.5.1 While most of the materials considered are known to be moldable, some are relatively new and unproven. We propose to modify one of our existing molds so it can be used for thermoplastic as well as thermosetting material and run a study of each of the materials to assure confidence that the ones selected can be considered production materials.

15.5.2 The parts so molded will be used for dimensional studies, and subjected to thermal shock and heat aging tests to evaluate durability and dimensional changes in the -200 to +200°C range.

15.6 Electrical Properties

15.6.1 Materials will be directly compared for electrical properties with specific emphasis on those pertinent to connector designs. These would include arc resistance, dielectric strength (at 200°C and also after water immersion) and insulation resistance (at 200°C and after humidity exposure).

16.0 <u>Results</u>

16.1 On conclusion of these tests and any others deemed advisable by NASA, including the final flame resistance and outgassing evaluation by NASA, we should be confident of a material selection capable of withstanding the severe combination of environmental, mechanical, and electrical stresses that may be encountered.

TABLE 13

PROPERTIES OF STRUCTURAL DIELECTRICS

Task III	UNITS								
Material Designation		AI-11	VESPEL SP-1	MELDIN PI	FEURALON P	GEMON 3010	XPI-MC154	XPI MC154-G10	YF1004
Supplier		Amoco	Du Pont	Dixon	Bemol Corp	General Elec	Amer Cyan	Amer Cyanamid	LNP
Basic Resin		Polyimide-amide	Polyimide	Polyimide	Polyimide	Polyimide	Polyimide	Polyimide	Polyimide
Filler		None	none	None	None	Glass fibers	None	Glass fibers	Glass fibers
Molding Classification		Proprietary	Proprietary	Proprietary	Proprietary	Thermosetting	Thermo plastic	Thermoplastic	Thermoplastic
Molding Ease		Questionable	Questionable	Questionable	Questionable	Fair	Very good	Good	Good
Shelf Life - Raw Material		N A	N A	N A	N A	-	No limit	No limit	No limit
Dimensional Capability		Questionable	Questionable	Questionable	Questionable	Good	Good	Good	Good
Dimensional Stability		Good	Good	Good	Good	Good	Good	Good	Good
Durability (Resist to Cracking, etc)		Questionable	Questionable	Questionable	Questionable	Good	Fair	Fair	Fair
Mechanical Properties									
Specific Gravity	GMs/cc	1 41	1 43	1 40	1 48	1 90	1 26	1 34	1 42
Flexural Strength, 25°C	PSI	23,400	14,000	11,800	16,800	56,000	18,000	20,500	16,000
Flexural Strength, 200°C	PSI	18,000(400°F)	7,000(600°F)	6,400(500°F)	11,400(500°F)	45,300(482°F)	10,000	16,400	
After 168 hrs/250°C, 25°C	PSI	21,500(1000/288°C)	12,000 (est)	10,000(100/700°F)	15,000 (est.)	45,000			
Impact Strength	Ft. Lbs/In	0 70	0 9	0 5	0 9	17 0	0 5	0 5	1 7
Electrical Properties									
Dielectric Strength, S. T.	Volts/Mil	400	560(080)	430	550(?)	500+	365	400	425
Diel Str., S x S, D48/50	Volts/Mil	-							
Volume Resistivity, 25°C	Megohms	0 8x10^{15}ohm/cm	10^{16}ohm/cm	5 8x10^{16}ohm/cm	10^{16}ohm/cm	9 2x10^{15}ohm/cm	2x10^{15}ohm/cm	1x10^{16}ohm/cm	2x10^{16}ohm/cm
Volume Resistivity, 200°C	Megohms		10^{13}ohm/cm						
Cond C-720/70/100	Megohms								
Surface Resistivity									
Cond C 720/70/100	Megohms	-							
Arc Resistance	Seconds	-	230(erratic)	182	220	50-180	155	80	135
Flame Resistance									
Flammability (Air)		Non-burning				Non-burning	Self-Ext	Self-Ext	Self-Ext.
ASTM D635									
MIL-M-14, Ign Time	Seconds								
MIL-M-14, Burn Time	Seconds								
Flammability (oxygen)									
Oxygen Index	%					60	24 5	Should be equal or better than XPI-MC 154	Should be equal or better than XPI-MC154
MSC-A-D-66-3(A)			See NASA						
Prop. Rate Up (6 2PSIA)	S E. (Yes or No)			Yes					
(16 5 PSIA)	S. E (Yes or No)		TM-X-53788						
Prop. Rate Dn. (6 2PSIA)	In /Sec.		No ignition in	000					
(16 5 PSIA)	In /Sec.		6 2 psia O_2						
Flash Point (6 2 PSIA)	°F(°C)			570°F					
(16 5 PSIA)	°F(°C)								
Fire Point (6.2 PSIA)	°F(°C)			600°F+					
(16 5 PSIA)	°F(°C)								
Outgassing									
Weight Loss, Air	(Hrs/°C)	500/288 1000/288	200/325						
Total	%	1 03 1 49	1 0						
Stabilized Rate	%/cm²/hr		0 Approx						
Weight Loss, Vacuum	(Hrs/°C/Torr)		(x/260/10^{-7})			(24/125/10^{-6})	(12/200/10^{-6})	(12/200/10^{-6})	
Total	%		<10^{-10}gm/sq cm sec			34%	0 9%	0 75%	
Stabilized Rate	%/cm²/hr								
Max. Service Temp	°F(°C)	550 (288)	600(315)	600(315)	600(315)	500+(260+)	440(225)	455(235)	500(260)
Radiation Resistance		Expected good	Excellent(10^9rads threshold damge)	Excellent(10^9rads threshold damge)	Excel(10^9rads threshold dmg)	Excel(10^9rads threshold dmg)	Excel(est)	Excel(est)	Excel(est)
Chemical Resistance		Excellent	Excellent (N G -Hydrazine, N_2O_4)	Excellent	Excellent	Excellent	Excellent	Excellent	Excellent

TABLE 13 (Continued)

Task III	UNITS							
Material Designation		302	M-91-101	MS2046L	Astrel 360	Teflon FEP110	TEFZEL 200	Kel-F
Supplier		Dow Corning	Dow Corning	Midsil Corp	3M	DuPont	Du Pont	3M
Basic Resin		Silicone	Silicone	Silicone	Polyarylsulfone	FEP	Ethylene TFE(ETFE)	CTFE
Filler		Lng glass fib	Glass & mineral	Short glass & silica	None	None	None	None
Molding Classification		Thermosetting	Thermosetting	Thermosetting	Thermoplastic	Thermoplastic	Thermoplastic	Thermoplastic
Molding Ease		Poor(cracks)	Fair	Fair	Fair	Fair-poor	Good	Good
Shelf Life - Raw Material			6 mo at 40°F	Refrig req'd	No limit	No limit	No limit	No limit
Dimensional Capability		Good	Good (est)	Good (est)	Good	Fair	Fair-Good	Good
Dimensional Stability		Good	Good (est)	Good (est)	Good	Good	Good	Good
Durability (Resist to Cracking, etc)		Poor(cracks)	Poor (cracks)	Poor (cracks)	Good	Good	Good	Good
Mechanical Properties								
Specific Gravity	GMs/cc	1 88	1 88	1 88	1 36	2.15	1.70	2.13
Flexural Strength, 25°C	PSI	19,000	10,000	9000	17,200			10,700
Flexural Strength, 200°C	PSI	7,000(250°C)			8,900 (260°C)			1,650(125°C)
After 168 hrs/250°C, 25°C	PSI	14,500	No signif chg 1000 hr		No signif chg 2000 hr		Unsatisfactory	Unsatisfactory
Impact Strength	Ft Lbs/In	10	0 28	0 3	5 0	No break	No break	3.1
Electrical Properties								
Dielectric Strength, S T	Volts/Mil	280	350	280	350(0 62)	400	2000(10 mil)	495
Diel. Str., S x S, D48/50	Volts/Mil							
Volume Resistivity, 25°C	Megohms	$9x10^{14}$ohm/cm	1 $4x10^{13}$ohm/cm	$2x10^{14}$ohm cm	3 $2x10^{16}$ohm/cm	$>10^{12}$	$>10^{16}$ ohm-cm	7 $5x10^{16}$ohm/cm
Volume Resistivity, 200°C	Megohms							
Cond C-720/70/100	Megohms	$4x10^{13}$(96/23/96)						
Surface Resistivity								
Cond. C 720/70/100	Megohms							
Arc Resistance	Seconds	240	290	250	67	Non-tracking		360
Flame Resistance								
Flammability (Air)		Self-Ext	Self-Ext	Self-Ext	Self-Ext.	Non-flammable	Non burning	Non-flammable
ASTM D635								
MIL-M-14, Ign Time	Seconds							
MIL-M-14, Burn Time	Seconds							
Flammability (oxygen)								
Oxygen Index	%							
MSC-A-D-66-3(A)								
Prop Rate Up (6.2 PSIA)	S. E (Yes or No)				No	No		Yes(6.2 psia)
(16.5 PSIA)	S E (Yes or No)							
Prop. Rate Dn. (6.2 PSIA)	In /Sec.				019			(Inconsistent
(16.5 PSIA)	In. /Sec.				039	010 app.		results
Flash Point (6.2 PSIA)	°F(°C)					600°F +		reported)
(16 5 PSIA)	°F(°C)							
Fire Point (6 2 PSIA)	°F(°C)					600°F +		
(16.5 PSIA)	°F(°C)							
Outgassing								
Weight Loss, Air	(Hrs/°C)							
Total	%							
Stabilized Rate	%/cm^2/hr							
Weight Loss, Vacuum	(Hrs/°C/Torr)	(125/295/10^{-6})	Similar to	(240/225/10^{-6})	(240/220/10^{-2})	(102/100/10^{-7})		
Total	%	0 7(run on DC307)	D. C 302	0 40	0 75	0 08		
Stabilized Rate	%/cm^2/hr	0023%/hr "			000			
Max Service Temp.	°F(°C)	550+(288+)			500(260)	400(205)	356+(180+)	375(190)
Radiation Resistance		$2x10^9$rads-usable	$2x10^9$rads-usable	$2x10^9$rads-usable	$1x10^8$rads-no effect	$50x10^6$rads brittle(air)		$1x10^7$rads usable
Chemical Resistance		Poor in some solvents	Poor in some solvents	Poor in some solvents	Excellent	Excellent	Excellent	Excellent

TABLE 13 (Continued)

	UNITS						
Material Designation:		Fluorcomp 905	Fluorcomp 803	RYTON PPS	RYTON PPS	FCR - 1261	EPOCAST X-87104
Supplier:		LNP	LNP	Phillips Petroleum	Phillips Petroleum	Firestone	Furane Plastics
Basic Resin:		FEP	CTFE	Polyphenylene Sulfide	Polyphenylene Sulfide	Polybutadiene	Polybutadiene
Filler:		Glass fibers	Glass fibers	40% glass fibers	Silica	Glass	Glass
Molding Classification:		Thermoplastic	Thermoplastic	Thermoplastic	Thermoplastic	Thermosetting	Thermosetting
Molding Ease:		Fair - good	Good			Good (est)	Very Good (est)
Shelf Life - Raw Material:		No limit	No limit			Good (6mo min.)	1 yr at 90°F
Dimensional Capability:		Good	Good			Fair (est)	Good (est.)
Dimensional Stability:		Good	Good			Fair (est)	Good (est)
Durability (Resist. to Cracking, etc):		Good	Good			Quite brittle	Good (est)
Mechanical Properties							
Specific Gravity	Gms/cc	2 22	2.19	1 34	1 64	2 05	1 90
Flexural Strength, 25°C	PSI	4,400	8,000	20,000	37,000	11,000	12,000
Flexural Strength, 200°C	PSI					25% retained	
After 168 hrs/250°C, 25°C	PSI					50% retained	7,200 (130/288°C)
Impact Strength	Ft. lbs/in.	0.3	1 2	0 3	0 8	0.25-0 5	0.5
Electrical Properties:		475		595	490	500	
Dielectric Strength, S.T.	Volts/Mil						450
Diel. Str., S x S, D48/50	Volts/Mil					1 5x10^15 ohm cm	
Volume Resistivity, 25°C	Megohms						10^14 ohm cm.
Volume Resistivity, 200°C	Megohms						
Cond. C-720/70/100	Megohms						
Surface Resistivity							
Cond. C 720/70/100	Megohms						
Arc Resistance	Seconds	Non-tracking				252	
Flame Resistance							
Flammability (Air)		Non-burning	Non-burning	Non-burning	Non-burning	Non-burning	
ASTM D635							
MIL-M-14, Ign. Time	Seconds						
MIL-M-14, Burn Time	Seconds						
Flammability (oxygen)							
Oxygen Index	%	95	83	44	44+	24 (can be improved)	
MSC-A-D-66-3(A)							
Prop. Rate Up (6.2PSIA)	S.E. (Yes or No)						
(16.5 PSIA)	S.E. (Yes or No)						
Prop. Rate Down (6.2PSIA)	in./sec.						
(16.5PSIA)	in./sec.						
Flash Point (6.2PSIA)	°F (°C)						
(16.5PSIA)	°F (°C)						
Fire Point (6.2PSIA)	°F (°C)						
(16.5PSIA)	°F (°C)						
Outgassing							
Weight Loss, Air	(Hrs/°C)						(130/288)(1000/200)
Total	%						1 5 9 0
Stabilized Rate	%/cm^2/hr.						
Weight Loss, Vacuum	(Hrs/°C/Torr)						
Total	%						
Stabilized Rate	%/cm^2/hr.						
Max. Service Temp	°F (°C)			500 (260)	500 (260)	392 (200)	392 (200)
Radiation Resistance		10^6 rads -threshold in air	10^7 rads-usable	No data	No data	No data	No data (est. good)
Chemical Resistance		Excellent	Excellent	Excellent	Excellent	Excellent	Excellent

Task III	UNITS						
Material Designation		EMC RXM 380-57C	EMC 114	EMC 500	E9747	Epiall 1914	Epiall 1988
Supplier		Pacific Resins & Chem	Pacific Resins & Chem	Pacific Resins & Chem	Fiberite Corp.	Allied	Allied
Basic Resin		Epoxy	Epoxy	Epoxy	Epoxy	Epoxy	Epoxy
Filler		Glass	Glass	Glass	Glass	Glass fiber	Long glass fiber
Molding Classification		Thermosetting	Thermosetting	Thermosetting	Thermosetting	Thermosetting	Thermosetting
Molding Ease		Excellent	Excellent	Excellent	Very good	Excellent	Excellent
Shelf Life - Raw Material		4 mo at 73°F	6 mo at 73°F	4 mo at 75°F		Good	Good
Dimensional Capability		Very good (est.)	Very good (est.)	Good (est.)	Very good (est.)	Excellent	Excellent
Dimensional Stability		Very good (est.)	Very good (est.)	Very Good (est.)	Very good (est.)	Excellent	Excellent
Durability (Resist to Cracking, etc)		Good (est.)	Good (est.)	Good (est.)	Good (est.)	Excellent	Excellent
Mechanical Properties							
Specific Gravity	GMs/cc	1.95	1.80	1.90		1.92	1.75
Flexural Strength, 25°C	PSI	17,500	16,630	20,100	16,000	20,000	20,000
Flexural Strength, 200°C	PSI				7,000	7,800 (350°F)	6,000 (350°F)
After 168 hrs/250°C, 25°C	PSI				14,000	23,000 (550°F)	1,000 (550°F)
Impact Strength	Ft Lbs/In	0.40	0.65	0.52	0.5	0.50	5.5
Electrical Properties							
Dielectric Strength, S T	Volts/Mil	880(30 mils)	400	840 (30 mils)	350	350	360
Diel Str, S x S, D48/50	Volts/Mil						
Volume Resistivity, 25°C	Megohms	6.3×10^{15} ohm cm	1×10^{15} ohm cm	1.4×10^{16} ohm cm	10^9	10^7+	10^7+
Volume Resistivity, 200°C	Megohms				10^4		
Cond C-720/70/100	Megohms				10^4		
Surface Resistivity							
Cond C 720/70/100	Megohms				10^4		
Arc Resistance	Seconds	185	150-180	180	180	187	145
Flame Resistance							
Flammability (Air)		(can be made		(can be made	Non-burning	Non-burning	Non-burning
ASTM D635		S E (non-burning	S E	S E (non-burning			
MIL-M-14, Ign Time	Seconds				150		
MIL-M-14, Burn Time	Seconds				150		
Flammability (oxygen)							
Oxygen Index	%						
MSC-A-D-66-3(A)							
Prop Rate Up (6.2 PSIA)	S E (Yes or No)						
(16.5 PSIA)	S E (Yes or No)						
Prop. Rate Dn. (6.2 PSIA)	In./Sec						
(16.5 PSIA)	In./Sec.						
Flash Point (6.2 PSIA)	°F(°C)						
(16.5 PSIA)	°F(°C)						
Fire Point (6.2 PSIA)	°F(°C)						
(16.5 PSIA)	°F(°C)						
Outgassing					Post cured		
Weight Loss, Air	(Hrs/°C)	(100/200)	(100/200)	(100/200)	(720/260)(2000/200)	(168/260)	(168/260)
Total	%	1.09	1.98	1.65	6% 1.8%	1.5	1.5
Stabilized Rate	%/cm²/hr.						
Weight Loss, Vacuum	(Hrs/°C/Torr)						
Total	%						
Stabilized Rate	%/cm²/hr.						
Max. Service Temp	°F(°C)	400(204)	420 (188)	450 (232)	500(260)	500(260)	450(232)
Radiation Resistance		10^9 rads usable	10^9 rads usable	10^9 rads usable	10^9 rads usable	10^9 rads usable	10^9 rads usable
Chemical Resistance		Excellent	Excellent	Excellent	Excellent	Excellent	Excellent

TABLE 13 (Continued)

	UNITS				
Material Designation:		EKONOL	EPIALL 2088	EPIALL 1288 Bx	GLASKYD 7100FR
Supplier:		Carborundum	Allied	Allied	Amer. Cyanamid
Basic Resin:		Heat Resist Polyest.	Epoxy	Epoxy	Alkyd
Filler:			Long glass fiber	Glass & mineral	Glass & mineral
Molding Classification:			Thermosetting	Thermosetting	Thermosetting
Molding Ease:		Poor	Excellent	Excellent	Very Good
Shelf Life - Raw Material:			Good	Fair	Excellent
Dimensional Capability:			Excellent	Excellent	Good (est.)
Dimensional Stability:			Excellent	Excellent	Very good (est)
Durability (Resist. to Cracking, etc):			Excellent	Excellent	Good (est.)
Mechanical Properties					
Specific Gravity	Gms/cc	1 45	1 80	2 05	2 33
Flexural Strength, 25°C	PSI	10,700	22,000	12,000+	8,500 to 11,000
Flexural Strength, 200°C	PSI	95% retained	6,200 (350°F)		
After 168 hrs/250°C, 25°C	PSI		13,000 (550°F)		
Impact Strength	Ft. lbs/in.		5 5	0 6 +	1.0 - 1.2
Electrical Properties:					
Dielectric Strength, S.T.	Volts/Mil	660	350	360	325
Diel. Str., S x S, D48/50	Volts/Mil			300+	
Volume Resistivity, 25°C	Megohms	10^{15}ohm cm +	10^7+	10^7+	
Volume Resistivity, 200°C	Megohms				
Cond. C-720/70/100	Megohms				2x10^4
Surface Resistivity					
Cond. C 720/70/100	Megohms				3 5x10^4
Arc Resistance	Seconds		140	180	180+
Flame Resistance					
Flammability (Air)		Self-exting	Non-burning	Meets criteria of DAC 56647 Category B, Douglas Missiles & Space Systems Div. Lab report Catalog No. PDL101,101 Serial No MP51,170 11/1/68	
ASTM D635			>90		106
MIL-M-14, Ign. Time	Seconds		<70		74
MIL-M-14, Burn Time	Seconds				
Flammability (oxygen)					
Oxygen Index	%				
MSC-A-D-66-3(A)					
Prop. Rate Up (6.2PSIA)	S.E. (Yes or No)				
(16.5 PSIA)	S.E. (Yes or No)				
Prop. Rate Down (6.2PSIA)	in./sec.				
(16.5PSIA)	in./sec.				
Flash Point (6.2PSIA)	°F (°C)				
(16.5PSIA)	°F (°C)				
Fire Point (6.2PSIA)	°F (°C)				
(16.5PSIA)	°F (°C)				
Outgassing					
Weight Loss, Air	(Hrs/°C)	2000/260	(168/260)	See above	(720/210)
Total	%	1 5%	2 2		3 6 (Exp Mod)
Stabilized Rate	%/cm^2/hr.				004% - 1 hr.
Weight Loss, Vacuum	(Hrs/°C/Torr)				
Total	%				
Stabilized Rate	%/cm^2/hr.				
Max. Service Temp	°F (°C)	500+ (260+)	450 (232)	450 (232)	400 (204)
Radiation Resistance			10^9 rads-usable	10^9 rads-usable	
Chemical Resistance		Excellent	Excellent	Excellent	Excellent

TASK IV

Final Report - Phase I

Task IV

Investigation of Elastomers For Electrical Connector Seals For Space Applications

17.0 Introduction

17.1 Our First Quarterly Report [24] described the essential requirements for elastomers in connectors, specifically the main joint seal and the wire sealing grommet. It became apparent that compounds based on du Pont Viton or 3M Fluorel provided the best chance of overall compliance because of their proven flame resistance in oxygen atmospheres.

17.2 At the same time the fundamental shortcomings of these materials also became evident, notably poor moldability and poor resilience.

18.0 Report

18.1 Further investigation into the fluorocarbon rubbers available indicated two more Fluorel materials worthy of study. These are Mosites #1087-JJ and Raybestos Manhattan L-3583-2. Both these materials are in the 55-60 durometer range necessary for grommets and available properties are listed in Table 14. Data is incomplete compared with the materials included in our first report and repeated in Table 15,but they appear comparable with du Pont's Viton VS 2001.

18.2 Since our last report, we have received some Fluorel L-3203-6 from D. E. Supkis, NASA, Houston for molding evaluation. The abbreviated study we were able to make confirmed our suspicions relative to moldability. We confined our molding to simple molds and still had difficulty in obtaining perfect samples. Greatest problem seemed to be from inability to get a proper cure as parts were inclined to be porous and contain blisters. We do feel more familiarity with the material would overcome this as far as simple moldings such as "O" rings or gaskets are concerned. The material is much too hard for use in connector grommets with the earlier mentioned materials being preferred. Earlier we had molded parts from Fluorel L-2231 from Raybestos Manhattan with no difficulty encountered on simple parts but with tearing of webs on standard grommets.

18.3 Mr. J. V. Owens of Raybestos Manhattan assured us of their cooperation in overcoming any molding problems we might later encounter should these materials warrant further study.

18.4 The whole fluorocarbon elastomer family as represented by 3M's Fluorel and du Pont's Viton have been rapidly improving. Disregarding flame resistance for the moment, the major inpetus has been in compression set. Both companies have been able to reduce compression set at all temperatures. For example, Viton E-60C has about the same set after 1000 hours at 392 °F as the original Viton A had after 70 hours [26]. Fluorel 2160 is comparable. As a result of these achievements, new specifications have been issued specifically to cover these materials. These are MIL-R-83248 and AMS 7280 and mark a major advance in state-of-the-art recognition.

18.5 du Pont also has a modified Viton designated LD-487 having lower temperature characteristics than the standard materials. Brittle point is -60 °F approximately and TR-10 is -31 °F. compared with -40 °F and -5 °F for Viton A. These are still a long way from -200 °C but do represent a substantial improvement.

18.6 Because there has been so much progress in these materials including our own success in developing Viton connector insert and grommet materials, it seems logical that they could be further improved in those directions considered advisable. This would be one our main efforts suggested for Phase II.

18.7 The alternatives to these materials are unsuitable in one area or another when compared with our present guidelines. The organic rubbers as a whole are all unsatisfactory from a temperature standpoint. Temperature resistance also eliminates the CNR or Nitroso rubbers developed by Thiokol which appear to be equal to the fluorocarbons in flame resistance in oxygen atmospheres. However, CNR is also listed in NASA 50MO2442 "ATM Material Control for Contamination Due to Outgassing" as an "unacceptable material" [19].

18.8 The Dexsil materials developed by Olin Matheson appear to have the heat resistance required but difficulties in manufacture have pretty well curtailed their progress to production status. These materials are reported capable of withstanding temperatures considerably higher than the silicone. Outgassing in hard vacuum was reported minimal, tests for 72 hours at 155 °C yielding only 49 ppm total organics and less than 5 ppm carbon monoxide [27]. The material was also self extinguishing in air, and flash and fire points are extremely high. Flammability tests conducted by NASA showed the samples tested were not self extinguishing in 16.5 psia oxygen [17].

18.9 Both of the above materials had a further disadvantage, price, with the CNR rubbers at approximately $600 per pound and Dexsil at $100 per pound. While we certainly will follow their progress we see no chance of their utilization in connectors at their present status.

18.10 Beyond these lie even newer polymers in various stages of development such as the perfluoroalkylene triazines and copolymers of tetrafluoroethylene and prefluoro (methyl vinyl ether), the former under investigation by Hooker Chemical and the latter by du Pont [28,29]. These are materials of the future, warranting close observation as they progress but hardly likely for serious consideration at this date.

18.11 The materials most commonly used in high performance electrical connector grommets and seals have been silicone rubber compounds. Both fluorinated oil resistant silicones, non-fluorinated silicone, and blends of both have been used.

18.12 Properly formulated silicone rubbers are capable of long life at 200 °C with minimum effects on mechanical and electrical properties. In general, they are also low in outgassing in vacuum or air at these temperatures. However, it is still necessary to assure absence of low molecular weight fractions and other volatiles which may be characteristic of specific compounds. As a rule this can be accomplished by high temperature curing, in extreme cases under vacuum.

18.13 At sub-zero temperatures, they range in brittle point from -90 °F (-68 °C) for the fluorinated stock to -178 °F (-116 °C) for the best low temperature materials. While this is still well above the -200 °C requirement, it is considerably below the best temperature recorded for the fluorocarbon rubbers. The brittle point does not by itself categorize the material as unsatisfactory at -200 °C. Tests on actual connectors employing both Viton and certain silicones in liquid helium and liquid nitrogen have failed to cause any permanent damage although some fluorinated silicones have cracked during this exposure.

18.14 The main obstacle to use of silicone rubbers remains flame resistance in oxygen atmospheres. While the basic polymers, even the fluorinated ones, have no inherent flame resistance, progress is being made through the use of additives. Prompted by Boeing Specification BMS 1-59 and McDonnell-Douglas DMS 2012, Dow Corning, General Electric, and Union Carbide have all produced rubbers which are flame retarding and quickly self-extinguishing in air.

18.15 Dow Corning Silastic 2351 and related compounds and General Electric CE5537 are not only flame resistant in air but also have other properties important to connector grommet design. These values are included in Table 16. These materials are not fluorosilicones and consequently have no substantial resistance to common oils and fuels. However, this would not appear necessary for this type of application.

18.16 Most recently Arthur D. Little, Inc., in a NASA development program

has succeeded in producing silicone formulations having oxygen index ratings as high as 0.60[30]. More usable compounds have oxygen index ratings from 0.40 to 0.50 and were self extinguishing in NASA tests in 50% oxygen at 10 psia. They were also slow burning in 100% oxygen at 6.2 psia.

18.17 These compounds utilize decabromodiphenyl (DBDP) as an additive to conventional silicone compounds such as General Electric SE-517. At the present time this additive is an experimental product and results are dependent on high purity.

18.18 Mechanical properties of these flame resistant silicones are reduced some by the additive but, from the limited data now available, might be usable. Tensile strengths over 700 pounds per square inch and elongations over 450% are quite typical and certainly within the parameters needed for grommets.

18.19 Low temperature resistance does not seem to be affected significantly by the additive but heat aging data is not sufficient to indicate whether it causes any detrimental effects.

18.20 In general, it appears that Arthur D. Little Inc. has made a substantial contribution to flame resistant silicone rubber technology and that considerably more remains to be done before the optimum material is developed. Their work has been limited at this time to one basic silicone reinforced gum, GE SE517, and one catalyst, 2,4-dichlorobenzoyl peroxide. Other gums and catalysts could be expected to provide improvements in some of the other properties which appear to be borderline with the present compounds incorporating DBDP.

18.21 These materials do not appear to be nearly as flame resistant as the Viton and Fluorel materials but are substantially better than the silicones now in use. They warrant a very serious consideration for use in grommets.

18.22 One other very feasible approach would be provision of a flame resistant face on the exposed surface of a silicone rubber grommet. This face would most logically be one of the Fluorel or Viton formulations. Such a combination could give us the best of both material systems at some sacrifice in size and cost.

19.0 Phase I Conclusions

19.1 Task IV of this program was aimed at finding an elastomer or elastomers which would be suitable for use in electrical connector main joint seals and wire sealing grommets with particular attention to the following:

a. Temperature extremes of -200°C to +200°C.

b. Non-flammable or self-extinguishing in oxygen atmospheres.

c. Negligible outgassing in space environments.

d. Other characteristics typical of general connector requirements.

19.2 It became evident early in our investigation that no one material was completely acceptable. No silicone material which has adequate performance capabilities in other respects has adequate flame resistance in oxygen. Silicone materials having resistance to flame in oxygen are practically useless in other characteristics and certainly unsuitable for grommets. The Fluorel and Viton materials which are adequate in flame resistance are restricted by low elongation, poor resilience, poor low temperature flexibility, and generally inferior moldability.

19.3 This leaves us with several alternatives which can be summed up as follows:

a. Elimination or reduction of the flammability in oxygen requirement to permit use of silicone rubber with generally superior performance in other respects. The ADL development in particular seems very promising.

b. If non-flammability in oxygen atmospheres under the most severe test conditions is mandatory, Fluorel or Viton compounds can be used, du Pont VS2001 appearing to be the best selection at this time. Wire holes in grommets will be restricted to a narrow range of wire sizes by the low elongation of the rubber. Sealing capabilities at subzero temperatures will be difficult to assure.

c. A composite grommet can be designed using silicone rubber for the sealing member with a Fluorel or Viton outer face for flame resistance and protection for the silicone rubber.

19.4 No problems are envisioned for the main joint seal. Normal design should bury them sufficiently to prevent exposure to flame. If this is not considered justifiable, Viton or Fluorel can be used, the selection being made from the NASA approved compounds.

20.0 Proposals For Phase II

20.1 Phase II of Task IV covering materials for elastomeric seals would fall largely into two categories which could be progressing concurrently.

20.2 First, would be the evaluation of materials which have already been found suitable by NASA, specifically the various Viton and Fluorel compositions. This will be largely a study of design adaptability with moldability being the chief factor. Web design of the grommet holes is expected to be crucial because of the low elongation of these materials. The ADL silicone improvements will also be thoroughly evaluated.

20.3 At the same time we would suggest a formulation program to provide an improved grommet material. This would be a two directional study, on one hand attempting to improve the shortcomings of the fluorocarbon materials while retaining their flame resistance, and on the other hand improving the flame resistance of the silicones without losing their desirable attributes.

20.4 At the conclusion of Phase II we would not only be able to recommend materials for the ultimate connector but could give positive design criteria to govern the successful uses of the materials. Should a composite design be most suitable, material selection would be simplified.

Table 14

Properties of Flame Retardant Elastomers

	Mosites 1087-JT	R/M L-3583-2
Durometer "A"	55	60
Tensile Strength, psi:	1200	1035
Elongation, %:	250	225
Tear Strength, ppi.	51	85
Specific Gravity	2.12	2.01
Brittle Point, °F	--	-29

Table 15

Properties of Flame Retardant Elastomers

	*Fluorel L-2231	Fluorel L-3203-6	Fluorel L-3251-3	Viton VS-2001
Original Properties				
Durometer (A)		82	80	53
Tensile Strength (psi)		657	500	830
Elongation (%)		362	325	260
Properties Post Cured,	(24/400°F)	(16/400°F)	(18/350°F)	(48/450°F)
Durometer (A)	71	97	96	57
Tensile Strength (psi)	2045	1558	1820	1240
Elongation (%)	210	75	75	230
Tear Strength (lbs/in)	122	128	61.5	95
Air Oven Aged, 7 Days at 400°F				
Durometer (A)	74	98	97	57
Tensile Strength (psi)	1720	1155	1787	1328
Elongation (%)	160	50	50	230
Compression set, 22 hrs/400°F (%)	55	64.5	71.9	43.7
Bashore Resilience (%)	6	5	4	3
Low Temp. Brittle Point, °F	-13	+ 17.6	8.6	-70

*Same as Mosite 1059

Table 16

Properties of Flame Retardant Silicone Elastomers

	Silastic 2351	GE CE5527
Durometer, Shore A:	52	50
Tensile Strength, spi:	1300	1400
Elongation, %:	600	600
Tear Strength, ppi:	190	180
Tension Set, %:	8	9
Oven Aged, 70 hours at 212 °F.		
Durometer Change:	+1	+3
Tensile Strength, psi:	1300	1300
Elongation, %:	530	550
Compression Set, %:	15	25
Low Temperature Properties		
Brittle Point	-98 °C (-144 °F)	Below -150 °F
TR-10 Point	Below -65 °F	Below -110 °F
Flame Resistance, Boeing BMS 1-59		
Extinguishing Time, Vertical (seconds):	5	6
Extinguishing Time, Horizontal (seconds):	2	0
Char Length, Inches:	1/32	0-1/16

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